TM 5-311

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

MILITARY PROTECTIVE CONSTRUCTION

(NUCLEAR WARFARE AND CHEMICAL AND BIOLOGICAL OPERATIONS)

TM 5-311

HEADQUARTERS, DEPARTMENT OF THE ARMY

[redacted]

MAY 1965

AGO 8731A

TECHNICAL MANUAL
No. 5–311

HEADQUARTERS
DEPARTMENT OF THE ARMY
WASHINGTON, D. C., *11 May 1965*

MILITARY PROTECTIVE CONSTRUCTION

(NUCLEAR WARFARE AND CHEMICAL AND BIOLOGICAL OPERATIONS)

			Paragraph	Page
CHAPTER	1.	CONCEPTS OF SHELTERS		
Section	I.	Introduction	1, 2	2
	II.	Shelter protection in the field	3–19	2
CHAPTER	2.	EFFECTS OF NUCLEAR WEAPONS		
Section	I.	Forms of energy in nuclear detonation	20, 21	22
	II.	Blast	22–29	22
	III.	Initial radiation	30–39	37
	IV.	Thermal radiation	40–42	47
	V.	Residual nuclear radiation and fallout	43–57	54
CHAPTER	3.	EXPEDIENT SHELTERS, INCLUDING USE OF EXISTING FACILITIES		
Section	I.	Introduction	58, 59	78
	II.	Conventional buildings	60–69	78
	III.	Fortifications as shelters	70, 71	99
	IV.	Mines, tunnels, and caves	72–79	101
CHAPTER	4.	CRITERIA FOR THE DESIGN OF SHELTERS		
Section	I.	Criteria for providing nuclear protection	80–82	112
	II.	Criteria for providing CB protection	83–90	120
CHAPTER	5.	ENVIRONMENTAL ENGINEERING		
Section	I.	Introduction	91–96	135
	II.	Disaster condition air supply	97, 98	144
	III.	Air conditioning	99–102	146
	IV.	Duct systems	103–105	154
	V.	Filter units	106–108	156
	VI.	Power, water, food, and communications	109–112	156
	VII.	Sanitation	113–115	164
	VIII.	Storage	116–119	166
CHAPTER	6.	DESIGN OF STRUCTURES		
Section	I.	Introduction	120, 121	169
	II.	Corrugated steel buried structures	122–130	171
	III.	Reinforced concrete buried structures	131–133	191
CHAPTER	7.	EXAMPLE DESIGN		
Section	I.	Introduction	134, 135	203
	II.	Sample situation	136–140	203
	III.	Planning	141–144	210
	IV.	Solution	145–148	210
APPENDIX	I.	REFERENCES		219
INDEX				221

* This manual supersedes TM 5–311, 11 August 1961, TM 5–310, 28 June 1946, and TM 3–350, 30 September 1954, including C 1, 1 March 1962.

CHAPTER 1
CONCEPTS OF SHELTERS

Section I. INTRODUCTION

1. Purpose and Scope

a. This manual is published for engineer troop commanders, staff officers, and personnel charged with the construction and operation of structures of a temporary or semipermanent nature which provide protection to personnel, equipment, and supplies against the effects of nuclear, chemical and biological, and conventional weapons.

b. The overall purpose of shelters, methods by which varying degrees of protection can be obtained, and general policies and guidelines for shelter construction and operation are explained. Along with the effects of conventional and chemical-biological (CB) weapons, the manual discusses the effects of blast and radiation of nuclear weapons on structures, and the effects that terrain and site adaptation have on the protective value of shelters. The utilization of existing facilities, such as conventional buildings, tunnels, and mines, to provide protection for personnel, equipment, and supplies is covered. Because the blast phenomena of nuclear weapons have the most damaging effects on the structural integrity of buildings, this manual includes the basic engineering principles of blast-resistant design. Standard drawings of structures designed to provide protection against specified levels of blast and nuclear radiation are presented. The manual further includes explanation of utility requirements, such as ventilation and sanitation facilities, and the special entrance appurtenances and devices needed for protective structures.

c. The protective shelters included in this manual are intended for use where vital functions can be performed, or where personnel can obtain protection from a hostile environment, or where critical items such as nuclear weapons or missile components can be stored.

2. Changes or Corrections

Users of this manual are encouraged to submit comments or recommended changes to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded direct to the Commandant, United States Army Engineer School, Fort Belvoir, Va. 22060.

Section II. SHELTER PROTECTION IN THE FIELD

3. Objectives of Shelters in the Field

A shelter is passive protection achieved by construction to reduce the effects of and speed recovery from an enemy attack. It must be emphasized at the outset that a shelter is not an end in itself but only a means to an end. The primary objective of a shelter is reduction of vulnerability. An increase in the enemy effort required to achieve a given degree of damage is, in effect, an increase in our own military strength. Construction planning must be based on the enemy's capability. Of paramount importance are the enemy's weapons and delivery means. In general, a safe-side philosophy must be followed in any consideration of the enemy's ability to attack vital facilities. The use of shelters may achieve the desired goal of a high assurance of the enemy's inability to inflict more than an acceptable level of damage on essential activities.

4. Protection from Effects of Conventional Weapons

a. Artillery and Infantry Weapons. Protection against conventional weapons is best provided by putting an adequate thickness of shielding material between the target and the weapon or weapon fragments. In the field, this is best done by digging in to give protection against direct fire weapons and tanks. Overhead cover gives added protection against artillery, mortars, bombs, or other aerial missiles. Such protection depends upon the strength and thickness of the cover. It should not extend above the ground far enough to present a target to direct fire weapons because its protective value is then reduced, although a sloping cover can help its protection potential. Surface structures covered with earth may provide protection comparable to subsurface structures, but they must be of stronger construction. Also, the thickness of earth for surface structure cover and the effort required to place and compact the earth may be so excessive as to discourage their construction. Normally, overhead cover affords protection against the overhead bursts of indirect fire weapons. An overhead earth cover of about 18 inches is enough to stop most fragments caused by those bursts. However, a direct hit from an indirect fire weapon can cause casualties through earth covers of up to 12-foot thickness. A protective cover built in functional layers supported by a roof of laminated planks gives the best protection per foot of cover thickness. Such a cover of 3-foot thickness will survive a direct hit from a 155-mm shell.

b. Bombs and Aerial Missiles. Bombs tend to produce individual fragments burst patterns similar to the surface bursts of indirect-fire weapons. Shelters and uncovered emplacements are, therefore, good protection unless a direct hit or near miss occurs, in which case only thick cover in functional layers will give protection (fig. 1). Aircraft rockets are similar to artillery direct-fire weapons except that aircraft have a greater capability for attacking a target at ground level. Aircraft machineguns and small caliber cannon are similar in their effects to small arms and small direct-fire infantry heavy weapons except that they also have a better capability for attacking low silhouette targets. Certain types of air-delivered weapons, such as small antipersonnel mines, may be dropped in high densities over wide

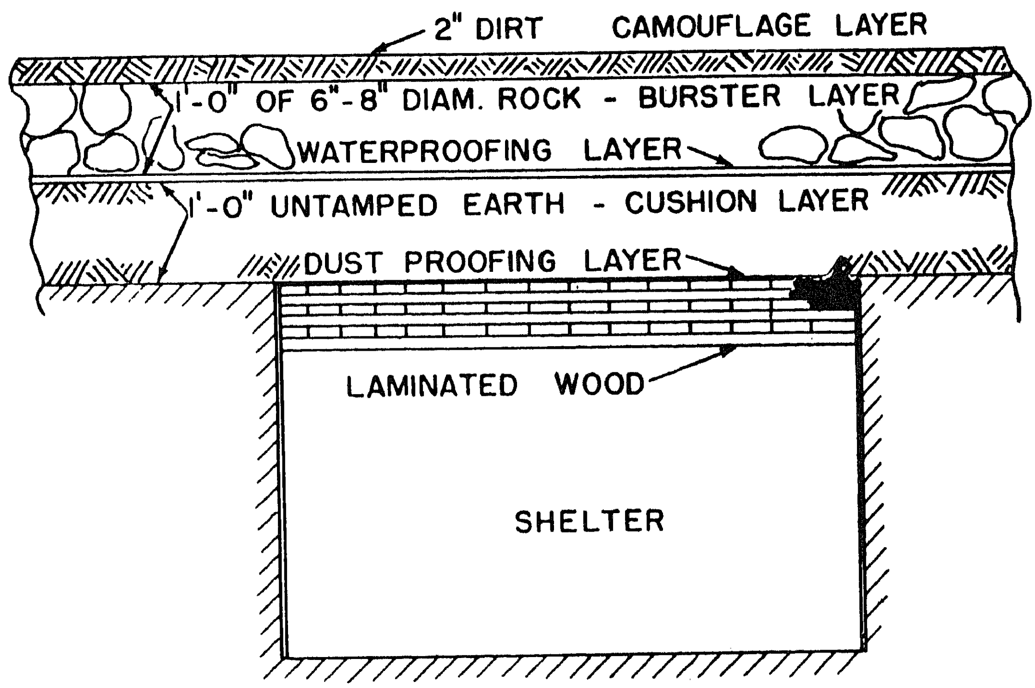


Figure 1. Typical overhead cover constructed in functional layers.

areas. Overhead cover which can resist penetration will provide protection from these.

c. Tracked Vehicles. Tracked vehicles can destroy or damage emplacements and shelters and cause casualties within them by their crushing action in addition to the use of direct-fire weapons. Small emplacements or shelters which are deep enough permit the surrounding earth to sustain the weight of tracked vehicles without crushing the fortification or injuring its occupants.

5. Protection from Chemical and Biological Weapons

a. Flame. Against flame (thickened or unthickened fuel delivered by flamethrowers, fire bombs, or flame field expedients), a shelter must prevent the burning gel or flame from burning or asphyxiating its occupants or destroying its equipment. Shelters can provide this capability by utilizing relatively small apertures and entrances which can be covered or closed to prohibit entrance of the burning products.

b. Chemical and Biological Agents. In order to provide complete protection against chemical and biological agents, a shelter must possess the unique features of controlling the entry of outside air either by sealing completely to insure airtightness or by providing a suitable filtering system which will remove contamination from air entering the shelter while maintaining a slight positive internal pressure. This latter requirement is imposed so that if there are leaks in the shelters they will be from inside to outside. Since virtually all chemical and biological agents are airborne in nature and because they are generally heavier than air, location and orietnation of the shelter will also be important factors when considering total protection afforded. When possible, shelters or the entrance to shelters, should be placed on high ground. Being heavier than air, chemical and biological agents have a tendency to accumulate in low-lying places; therefore, deep emplacements or emplacements located in gullies or valleys will usually increase the agent hazard. If practicable, shelters including chemical-biological protection should be oriented to take advantage of the prevailing or local wind direction (fig. 2). Shelters designed with their entrances perpendicular to the airflow or on the downwind side of a hill are less likely to become contaminated than those with entrances built on the upwind side. Entrances perpendicular to the airflow are best since droplets and solid particles will have a tendency to settle and accumulate on the downwind side because of reduced wind velocity. Against liquid contamination, either on the ground or in spray, shelters with overhead cover and protected apertures will give a reasonable degree of protection unless such contamination is inadvertently introduced into the shelter on clothing or equipment.

6. Protection from Effects of Nuclear Weapons

The effects of nuclear weapons from which protection of personnel and equipment is required are—

a. Blast

b. Initial nuclear radiation.

c. Thermal radiation

d. Residual radiation

7. Protection from Blast Effects

The blast effect of nuclear weapons acts on personnel within a shelter as well as on the shelter itself. There are direct effects, such as overpressure and drag loading, and indirect effects which cause physical injury to the occupants and loss of protection from other effects of nuclear weapons (and conventional, chemical, and biological weapons) resulting from destruction of the shelter.

a. Protection from Direct Effects.

(1) *Overpressure.* The effect of overpressure alone on personnel is, with one exception, not militarily significant. The pressure required to cause serious casualties is so high that personnel exposed to such pressure will normally also be exposed to lethal indirect blast effects and lethal radiation doses. Multiple reflections of the blast wave inside a shelter may, however, build overpressure up to significant levels. Casualties from the effects of direct overpressure which result in combat ineffectiveness can occur at 15

to 20 psi (1.05 to 1.5 kilograms per square centimeter). While the threshold for lung injury is 15 psi, severe lung damage begins to occur above 20 psi. The long duration of pressure pulse from nuclear weapon bursts will

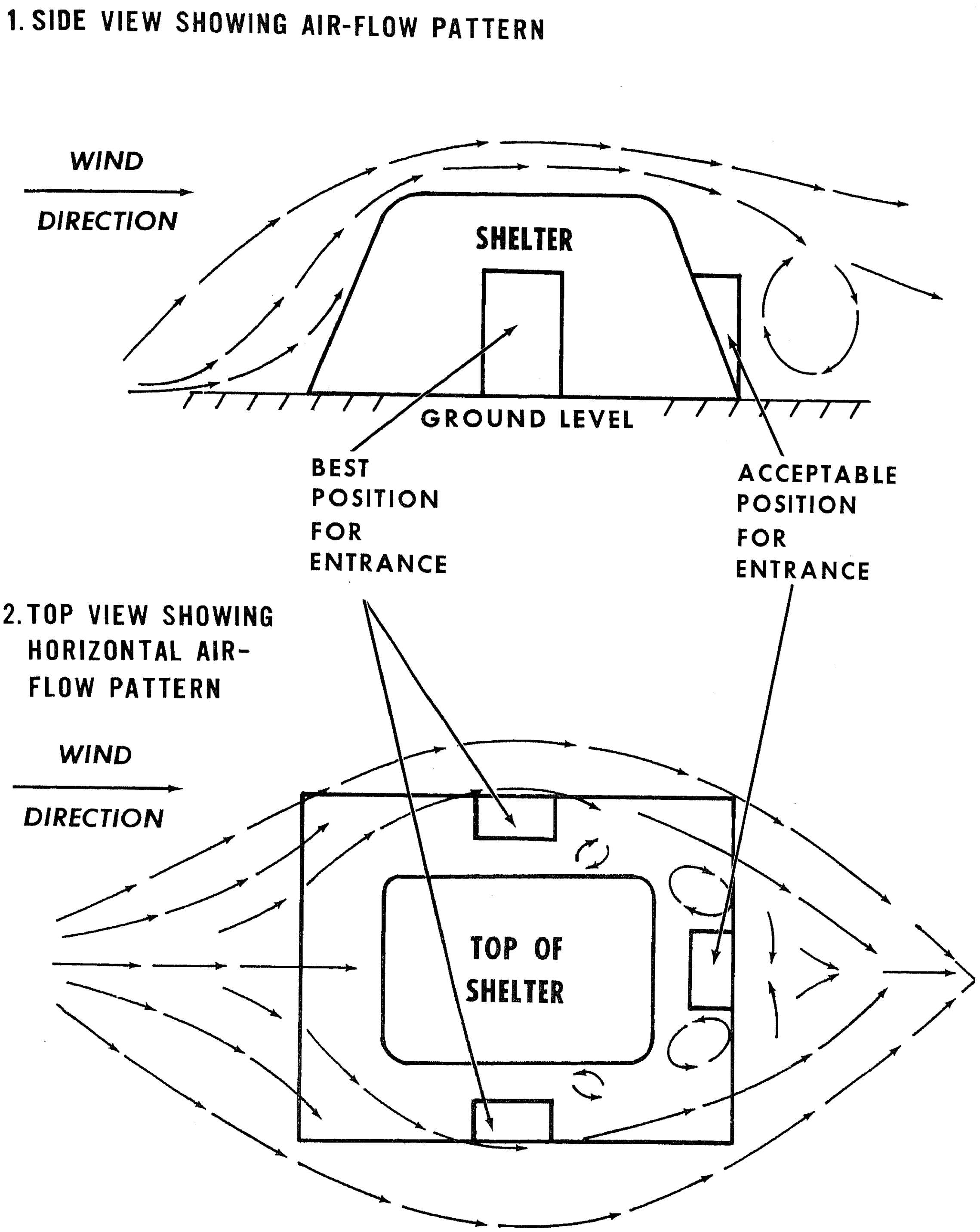


Figure 2. Variation of airflow around shelter entrances.

cause 50 percent casualties, or combat ineffectiveness, at the 39 psi (2.7 kilograms per square centimeter) pressure level, for yields of 100 KT. While the threshold for eardrum rupture occurs around 6 to 7 psi (422 to 492 grams per square centimeter) and the average for 50 percent eardrum fracture occurs at about 24 psi (1.7 kilograms per square centimeter), this condition alone is not considered to reduce combat effectiveness significantly. However, at blast overpressures in the 20 to 33 psi range, ear damage may involve the vestibulary apparatus and small bones of the inner ear, with resultant dizziness and deafness that may be severe enough to warrant evacuation. The use of blast-proof entrances will reduce this hazard.

(2) *Drag loading.* Belowground shelters and emplacements give good protection from drag loading (or dynamic pressure caused by the winds behind the blast front). Within the position itself, the area near doors and entranceways is most susceptible to drag effects (dynamic pressure) and incoming debris. This is especially true in

al-
s are
tifica-
tions. The degree of protection provided by a foxhole against injury resulting from translation is not too well known at present. However, a foxhole should provide appreciable protection if it is deep enough to prevent the occupant from being thrown out. (For further information on drag loading, see paragraph 25*c*.)

b. Protection from Indirect Effects.

(1) *Physical injury.* Well designed and well constructed positions can provide some protection from physical injury resulting from the collapse or partial failure of an emplacement or shelter due to drag loading, air-induced ground shock, or tree blowdown. Subsurface fortifications used in conjunction with low parapets provide the best protection in forested areas. Structures which protrude above the ground require overhead cover strong enough to support fallen trees. Damage to an emplacement or shelter which is severe enough to produce physical injury to its occupants will usually result in a loss of protection from other weapons effects. Means of preventing such loss are discussed in the following paragraphs.

(2) *Debris hazard.* If an individual is inside an emplacement or shelter, he has considerable protection from flying debris, depending on the design of the position and the amount of equipment within the position which might itself form a debris hazard. Small, deep, relatively closed positions such as foxholes provide the best protection. Wide, shallow, open positions such as artillery emplacements provide the poorest protection. The protection provided by an emplacement or shelter can be improved if the loose equipment within is kept to a minimum. This is because artillery weapons and equipment are heavy and difficult to anchor in an emplacement, and they are a hazard to personnel. Crews should remain in the emplacement only while actually engaged in firing the weapon.

(3) *Loss of protection in open emplacements.*

(*a*) *Unrevetted.* Blast damage to an unrevetted emplacement is caused by the failure of the soil to withstand air-induced ground shock. Soils vary in their susceptibility to this ground shock. In most soil firm enough to otherwise sustain an unrevetted emplacement, 25 psi (approximately 1,758 grams per square centimeter) or more will normally be required for actual wall collapse.

Unrevetted walls in a cohesive soil may show almost no structural damage while the same unrevetted emplacement in a less cohesive soil, such as sand, will collapse. However, an estimate of soil stability based only on cohesive qualities is not valid because of such variable characteristics of soil as previous disturbance and moisture and air content. The degrees of damage shown in table I for unrevetted emplacements are based on the level to which the emplacement was filled as a result of the introduction of dust and debris. (Shock susceptible soils such as loess can be expected to fail at much lower overpressure ranges.) Dust and debris may make weapons temporarily inoperative and cause casualties by choking or trapping the emplacement occupants.

(*b*) *Revetted.* The blast overpressure necessary to collapse revetted emplacements depends upon the soil type, the revetment material and the construction procedure used but will normally exceed that required to collapse unrevetted emplacements. Revetting will not prevent fill damage resulting from blown-in material, so table I will also generally apply to revetted positions in loose gravelly soil.

(4) *Loss of protection in covered emplacements.* Overhead cover for emplacements and shelters has considerable importance in protection from the indirect effects of blast. Unless the overhead cover is well constructed it can lessen the overall protective value of the emplacement or shelter since its failure may result in direct injury to the occupants as well as a greater probability of their injury from other effects. The forces acting on the overhead cover are produced by its own weight, the differential pressure on its faces, the impact of the pressure wave, and if above ground, the drag pressure. Overhead covers above ground have a tendency to be blown away while those level with or below the ground surface may tend to fail either inward or outward. Inward failure of cover results in a high probability of injury to the occupants.

Table I. Fill Damage to Unrevetted Open Subsurface Emplacements (Loose Gravelly Surface)

Overpressures		Degree of damage
psi	gram/sq cm	
20 psi	1,406	Severe
12 psi	844	Moderate
4 psi	281	Light

Severe ---------- At least 50 percent filled.
Moderate -------- Less than 50 percent and more than 10 percent filled.
Light ----------- Up to and including 10 percent filled.

(5) *Loss of protection in surface shelters.* Surface shelters are subject to the full force of the drag loading resulting from the blast effect of a nuclear explosion. Such loading can be critical at relatively low overpressures, particularly if there are openings above the surface. Streamlining the silhouette with earth cover will reduce the drag load, provided the earth cover has a slope less than 1 on 4 and extends a distance of twice the structure depth beyond the structure wall. The protection from tree blowdown if a tree falls on the shelter would depend on the construction of the shelter.

(6) *Loss of protection in subsurface shelters.* Since this type of shelter is underground, it is not subject to the drag-loading of the blast effect and can withstand higher blast overpressure than surface shelters. The effect of blast on the overhead cover of a subsurface shelter is essentially the same as that described in (4) above for covered emplacements.

(7) *Shelter system.* To develop a nuclear blast resistance, a shelter or a shelter system must be completely enclosed, that is, as close to airtight as possible. It must be air tight to prevent the intrusion of the overpressure front.

This is a primary difference in construction between a conventional (HE) shelter and a shelter against nuclear weapons. Both the conventional and nuclear shelters inherently have a preponderance of structural strength. However, the conventional shelter tends to concentrate the strength of the shelter in the roof system, that is, in laminated roofs, burster layers, and the like. In contrast a nuclear shelter must have equal strength at all points, since overpressure acts like hydrostatic (liquid pressure) loading and is not lessened significantly at moderate depths.

8. Protection from Initial Nuclear Radiation

In a nuclear explosion, energy is produced as a result of the redistribution of protons and neutrons in the nuclei of atoms. Nuclear interactions that produce such energy are called *fission* and *fusion.* In the fission process, a free neutron enters the nucleus of a fissionable atom (uranium or plutonium), causing it to divide into two smaller parts and thereby releasing a large amount of energy. In the fusion process, a pair of light nuclei fuse together to
he nuclear
n act only
cture and have
of the structure itself
lear radiation consists
gamma radiation and
iation.

...a Radiation.

ription. The gamma radiation which is produced by a nuclear explosion during the first minute after the burst is known as initial gamma radiation. This radiation cannot be detected by the human senses, but it can produce casualties if personnel are not shielded from it. Because radiation spreads over larger and larger areas as it travels away from the point source of the explosion, the intensity of radiation will also decrease with distance away from the source, so that the dose received will be inversely proportional to the square of the distance from the point of origin. Gamma radiation is also absorbed and decreased (or attenuated) to some extent when it must pass through any material including air. There is an attenuation factor to allow for decrease in intensity due to absorption and scattering of gamma rays by the intervening atmosphere. It is not possible to absorb gamma radiation completely, but if sufficient thickness of material is placed between the source of gamma radiation and an individual the radiation dose he receives becomes negligible.

(2) *Protection afforded by emplacements and shelters.* The gamma radiation affecting occupants of emplacements and shelters is in two components (fig. 3)—the direct or line-of-sight radiation, and the scatter radiation. At distances at which personnel in emplacements may be expected to survive a nuclear burst, at least 50 percent of the incident gamma dose will be from the scatter component. This percentage increases with the distance, so that for bursts of 10 (KT) or higher, on an emplacement or shelter in which personnel may be expected to survive,

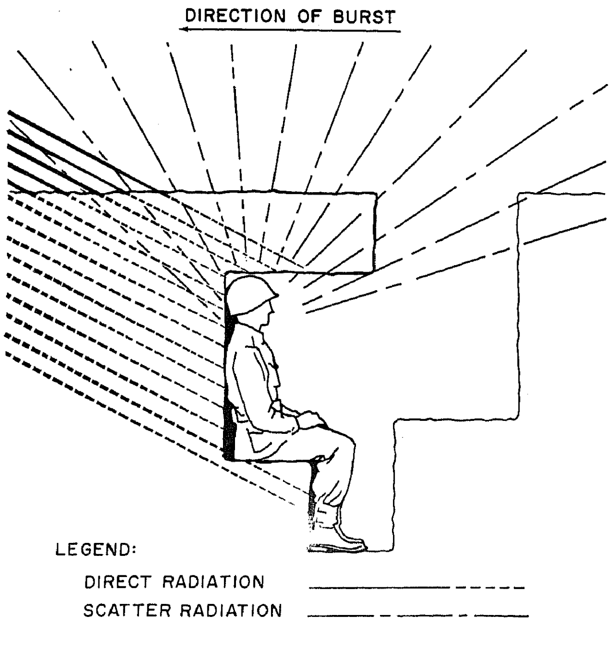


Figure 3. Effect of gamma radiation from a low airburst on occupant of an open emplacement.

an average of 75 percent of the gamma dose will be from scatter radiation. An emplacement or shelter, such as a deep foxhole, which provides allround shielding for the occupant against scatter radiation, but which may allow direct radiation (such as that from a high airburst) to enter, provides better overall protection than an emplacement or shelter which provides complete protection from direct radiation but does not provide allround protection against scatter radiation.

b. Neutron Radiation. Neutrons produced by the explosion of nuclear weapons behave somewhat like gamma rays. Neutrons scatter more than gamma rays; as a result, emplacements and shelters with openings allow more neutrons than gamma rays to enter. Earth, however, provides better shielding from neutrons than from gamma rays with the result that a well baffled entrance to an emplacement or shelter reduces the percentage of neutrons to gamma rays which enter the structure. Properly constructed emplacements and shelters provide substantial protection against neutron radiation.

9. Protection from Thermal Radiation

a. Importance. The protection of personnel from burns resulting from direct exposure to thermal radiation is a problem of large proportions due to the great range to which this effect extends for the higher yield weapons. The task of protection is increased by the fact that casualties may also be caused indirectly as a result of of fires in forest and builtup areas. Under certain circumstances (dry weather, forests subject to easy ignition, and high winds) the overall threat from the direct and indirect results of this effect may exceed that of all other effects, except fallout, combined.

b. Protection from Primary Effects. Thermal radiation causes direct casualties only on persons in the line of sight of the source of the thermal radiation. Personnel in the open or in uncovered emplacements can be provided some protection by any type of clothing that covers the body, including protective clothing. A protective cover such as a shelter half, blanket, or poncho placed over the individual will aid in stopping direct thermal radiation. An emplacement or shelter which provides significant protection from nuclear radiation normally will provide protection from direct thermal radiation.

c. Protection from Secondary Effects. Fires in forests and builtup areas may result from direct thermal radiation. Protection against them is usually beyond the capability of the individual. Individual emplacements and shelters will normally give their occupants adequate insulation from the heat of the fire but cannot prevent suffocation over extended periods. Personnel in tanks and armored carriers will be shielded from the fire if they can receive enough oxygen and the vehicle itself does not catch fire. If time or other considerations do not permit a quick evacuation from the fire area, personnel in vehicles should dismount and seek shelter in emplacements or shelters which have provision for ventilation.

10. Protection from Residual Radiation

a. Neutron-Induced Radiation. This type radiation results from radioactivity produced in certain types of soil by neutrons produced during the nuclear explosion. It exists in a circular pattern around ground zero, and primarily in the ground area directly below low airbursts. Personnel in emplacements or shelters in an area which receives significant amounts of this type of residual radiation will probably have become casualties from other effects. Areas in which fortifications are to be constructed should be monitored to detect the presence of radiation if there are indications that the area was near the ground zero of a nuclear burst.

b. Fallout.

(1) *Radiation from fallout.* The radioactive dust and debris particles which fall back to the ground (fallout) from surface or near surface bursts present the most difficult residual radiation protection problem. Personnel in emplacements and shelters in fallout areas are subjected to radiation from two major sources. One is the scatter gamma radiation from radioactive particles in the surrounding (out to several hundred feet) fallout areas; the other is the direct gamma radiation from radioactive particles which

fall or drift into or on the overhead cover of the emplacement or shelter.

(2) *Protection provided by emplacements and shelters.* Emplacements and shelters protect against scattered gamma radiation as described in paragraph 8*a*(2). Protection against radiation from radioactive particles (fallout) is obtained by keeping them out of the fortification itself and by providing a thick overhead cover to attenuate the radiation from any particles which do fall on or near the emplacement or shelter.

(3) *Permanent overhead cover.* Earth or other thick overhead cover on a properly designed emplacement or shelter will attenuate radiation resulting from any fallout deposited on it. The overhead cover may be of such a design that fallout particles driven by the wind tend to collect above the shelter and actually increase the dose rate of the radiation within the shelter. An emplacement or shelter should be constructed so that drifting as well as falling particles will not be concen-

ditch or
nately a
an em-
ercept or
This of-
mount
upants

cover. When a
or other tem-
r is used to ex-
fallout from an open emplacement the particles which collect on the temporary overhead cover should be periodically disposed of. This should be done well away from the emplacement so that they do not reenter it before the overhead cover is replaced. This type of overhead cover *only excludes* the particles and does not attenuate radiation from them.

11. Comparison of Protection Required from Different Effects of Nuclear Weapons

As interrelation exists between certain effects of nuclear weapons which governs the type and amount of protection from each effect which are required to provide the desired level of overall protection. The effects for which this interrelation is particularly significant are blast and prompt nuclear radiation. Protection from each of these effects must be balanced. No real protection is gained by revetting an open foxhole in which the occupants will receive 5,000 to 10,000 rad of prompt nuclear radiation before failure of unrevetted foxhole walls would occur. The occupant will become a casualty whether the foxhole is revetted or not. Likewise, no real protection is gained by providing an extremely low transmission factor for an emplacement or shelter not built to withstand the level of blast overpressure which would accompany the dose rates of radiation it can withstand. The ideal emplacement or shelter is one which provides comparable degrees of protection for its occupants against the effects of blast and initial nuclear radiation at the ranges at which casualties would occur to personnel inside it. This balanced protection cannot be achieved precisely, because changes in weapon yield and type change the relationship between the casualty radius from nuclear radiation and from blast effects. As a general rule, protection from prompt radiation is more important in low airbursts of small yield weapons and protection from blast is more important in high yield weapons.

12. Comparison of Protection Required from the Effects of Nuclear, Conventional, Chemical, and Biological Weapons

Similarities exist in the protection required against each of these types of weapons. These similarities aid greatly in the employment of a single emplacement or shelter to provide balanced protection.

a. Protection is provided from the blast effect of nuclear weapons by the use of defilade or by the use of low streamlined silhouettes and strong construction. This includes protection from damage to individual fortifications from tree blowdown. These same measures are used to provide protection from direct fire artillery and small arms weapons and from low level aircraft strafing and rocket attacks. With respect to type of construction, protection from the blast effect of a nuclear weapon requires

strength, mass, and streamlining. Protection from direct fire weapons requires both strength and considerable thickness of relatively impenetrable materials. The requirements for protection from both the blast effect of a nuclear explosion and conventional direct fire must be considered in employing an above-ground emplacement or shelter. The blast effect of the nuclear weapon generally governs the structural strength and shape; and the penetration by direct fire weapons governs the thickness and composition of protective shielding.

b. The requirements for protection against nuclear radiation are similar to requirements for protection against fragments from indirect fire artillery and bombs, as well as some types of air delivered weapons. Basically, both require a minimum diameter, maximum depth, excavation in defilade, overhead cover with a minimum of aperture or entrance area, and baffles in entranceways wherever possible. Generally, protection from conventional weapons will establish a requirement for minimum desirable thickness of cover. Protection from nuclear radiation will, in most cases, govern the required thickness above this. Depending on materials available and assuming good construction, about 12 to 24 inches (30.5 to 61 centimeters) of overhead cover normally will protect from shell fragments. Eighteen inches of earth over half a foxhole will reduce the total gamma radiation dose from a low airburst to about 0.7 of its value on an open foxhole. This decreases the distance from ground zero at which the occupant of the foxhole would be safe by about 100 yards (91.5 meters). Changing the thickness of the half cover to 12 to 24 inches (30.5 to 61 centimeters) of cover would not change this distance appreciably. Thus thickness of partial overhead cover normally should be based on protection from conventional weapons. When full cover is used, however, and there is little or no line of sight access of radiation into the shelter, radiation attenuation outweighs conventional weapons effects in governing the thickness of earth cover. In such a case, *for example,* a change from 12 to 24 inches of earth cover can be expected to reduce by more than half the initial nuclear radiation dose received by the occupant.

c. Fortifications providing good protection against initial radiation usually will provide excellent protection against fallout radiation if steps are taken to exclude the fallout particles.

d. Fortification characteristics required for the exclusion of chemical and biological agents will include those necessary against conventional or nuclear attack but will also incorporate additional features necessary to control air coming into the shelter. It must be borne in mind, however, that these characteristics would not appear as separate entities, but would be incorporated with characteristics common to other weapons systems as described in *a* through *c* above.

(1) The basic characteristic for a shelter to protect against effects of chemical and biological contamination is airtightness or a suitable filter unit which can remove contamination from incoming air and maintain a slight positive internal pressure.

(*a*) The effectiveness of the unventilated method involving sealing alone depends largely upon the tightness of seal. When the outside atmosphere is contaminated with chemical or biological agents, entry into or exit from the shelter breaks the seal and may cause interior contamination. With some agents, the shelter may continue to be used even though the interior has a low level of contamination; however, with other agents, such as those of the G-series, the level of contamination required to produce casualties is very low. Under this latter condition, the shelter cannot be occupied without the use of individual protective equipment. Further, because sealing creates a stagnant air supply inside the shelter, occupancy can be for relatively short periods only before intolerable environmental conditions occur.

(*b*) The ventilated shelter, achieved by use of filtering equipment, provides the best means of protection against chemical and biological contamination. The effectiveness of this method is dependent on a continuous supply of pure air and the mainte-

nance of a slight constant overpressure (of approximately 0.5-inch water) inside the shelter. Entry into or exit from this type shelter will not necessarily reduce the degree of protection afforded; and because a continuous supply of pure air is introduced into the shelter, no reliance upon a stagnant air supply is necessary.

(2) An airlock system is a definite requirement if entry into or departure from a ventilated shelter is to be made while under a CB environment. Inclusion of this stage prevents complete loss of pressurization inside the shelter thereby preventing any possible backdraft from forcing contamination inside. A similar airlock system can be used with an unventilated shelter to serve as an emergency entrance system under a CB environment and to act as a barrier to possible infiltration of CB agents.

(3) A decontamination area located im-

...tmosphere
...ee of in-
...troducing
...ne shelter.
this capability
...nstruction or
...ly in the com-

...l Protective Measures

...onstruction covers both opera-...al and physical protective measures, both in the continental United States and in overseas logistical and tactical installations, which will help the United States to survive an initial attack, recover, and successfully prosecute a war. While this manual is primarily concerned with the physical protective measures, it is important that the operational measures be understood and incorporated in protective construction planning. These operational protective construction measures include—

a. Dispersion. Dispersion is that operational measure which places essential facilities at physically separate locations to reduce the magnitude of losses from enemy attack. The policy of the United States encourages or requires that new facilities and major expansions of existing facilities important to national security be located, as far as practicable, so as to reduce the risk of damage. The policy also encourages or, when appropriate, requires the incorporation of protective construction features be incorporated in new and existing facilities to help resist weapon effects. The distance of a facility from the probable center of destruction is the controlling factor in reducing the risk of damage to such facility. In determining the appropriate distance of separation, all relevant factors will be considered, including—

(1) The most likely objects or targets of enemy attack such as certain military, industrial, population, and governmental concentrations.

(2) The size of such targets.

(3) The type and size of the known or suspected enemy weapons and the destructive power of the large-yield weapon or weapons suitable to the particular target.

(4) The gradation of pressures, initial nuclear radiation, and thermal radiation at various distances from assumed points of detonation.

(5) The characteristics of the proposed facility, including underground and builtin protective construction features, with respect to its resistance to nuclear, chemical, biological, and conventional weapons.

(6) The degree of damage which a facility could sustain and still operate.

(7) The ground environment or natural barriers which might further protect the facility.

(8) The economic, operational, and administrative requirements in carrying out the function of the facility.

(9) While no single distance standard and no single set of protective construction specifications against nuclear, chemical, and conventional weapons are feasible for all situations, the above factors will be applied so as to achieve the most practicable solution for a specific situation.

b. Duplication. Duplication provides alternative minimum operational facilities at separate locations, so if one facility is destroyed, its mission may be assumed by another. Alternate facilities may or may not be fully and continuously operational.

c. Concealment. Concealment includes all those measures which reduce the enemy's ability to detect or identify a facility as a target. Concealment is generally more applicable to the theater of operations than the zone of interior where the location of long-standing, permanent installations is probably well-known to the enemy. This method should never be neglected, since it is a simple and inexpensive means of reducing the likelihood of attack.

d. Superimposition. In many areas there is not enough space, even with the use of field fortifications, for installations to disperse satisfactorily, each in its own area, without attempting to attain unduly high levels of physical protection. A method of compensating for this shortage of space is the use of the technique of superimposition. In applying this technique, unlike installations are stationed close together and like installations are separated. By this means a command can insure that a given nuclear attack cannot entirely eliminate a specific capability of the command. Similar installations could be placed far enough from each other so one nuclear weapon could not destroy two installations of the same type. Losses would then be balanced with less serious overall effect. Superimposition eliminates the necessity for excessively high levels of protection, demanding high troop and logistical effort. There is, however, this important limitation on the use of superimposition—An installation of a type having a high probability of attracting a nuclear attack, or dummy or decoy installations designed to attract fire, should not be placed near other installations.

14. Physical Protective Measures

a. Categories of Physical Protective Measures. Physical protective measures are employed to harden essential facilities to withstand a specified level of exposure. Physical protection is considered under three structural categories as given in FM 100–1 (Doctrinal Guidance) (U).

(1) *Field fortifications — individual and unit construction.* These are emplacements and shelters of temporary construction which can be constructed with reasonable facility by using units with no more than minor engineer supervisory and equipment participation. Such emplacements and shelters are discussed in chapter 3.

(2) *Field fortifications—engineer construction.* These are emplacements and shelters of temporary construction which require construction by engineer troops with or without help from using units. This manual deals with temporary protective shelters for personnel, materials, and equipment which fall within this category of physical protection.

(3) *Semipermanent shelters.* These involve shelters of a more permanent type normally constructed in peacetime in CONUS and overseas for particularly vital installations. They may also be used in wartime in CONUS or in stable oversea areas for particularly vital installations. This manual covers those semipermanent shelters which are within the construction capability of engineer troop units.

b. Guidelines for the Employment of Physical Protective Measures.

(1) *Engineer responsibility.* In general, the command or district engineer will provide information to the commander on the degree of protection that can be realized for various expenditures of construction effort, time, and materials. He will make recommendations based on his comparison of the relative values of additional protection against the added engineer effort required.

(2) *Priority determination.* The relative tactical importance of facilities and activities as well as the acceptable minimum protection thereof will be determined by theater and area commanders. Advice and assistance of division and district engineers will be available to CONUS army comman-

ders and chiefs of technical services. Oversea commanders will use the services of command engineers and division and district engineers.

(3) *Integration into plans.* Shelters must be integrated into existing strategic, tactical, and logistic concepts and must provide balanced protection against all weapon effects which may be encountered. Semipermanent protective facilities may provide for continuous day-to-day operations rather than for use solely as "emergency shelters." All shelter systems with associated monitoring and warning devices, must insure that the intended occupants may physically reach the protection of the shelters in a reasonable time.

(4) *Construction personnel.* Engineer and other troop effort available for the construction of semipermanent shelters will continue to be at a minimum. Civilian contract construction firms or indigenous labor and equipment will be used where possible. Maximum use will be made of existing facilities.

ort

lations repre-
. Administra-
lude facilities
ters, hospitals,
provide these in-
vel of protection by
t and shelter construction
vely expensive except under
circumstances. Other means must be used which reduce the fortification and shelter effort to within reasonable limits. Dispersal reduces vulnerability considerably. Effective dispersal of unprotected installations, however, introduces major problems—efficiency, security, and reduction of control capabilities. Engineer effort may still be prohibitive because of the extended road (and to the rear, rail) nets required, and because of the demand to build in the dispersal areas additional facilities considered essential by the various technical services. The total area required to provide adequate protection through dispersal alone can be prohibitive. This paragraph is devoted to means which can be taken to provide the maximum possible protection of administrative support installations without introducing excessive requirements for emplacement and shelter construction effort, and without requiring excessive dispersal.

a. Protection Objective. The basic objective of protection for an administrative support installation is to insure that it can carry on its assigned mission after a nuclear attack. This requires preservation of personnel essential to accomplish the mission and preservation of essential stored and operating supplies and equipment.

b. Factors Involved. Many factors are involved in providing installation protection. Some of them affect the levels of fortifications required more directly than others. This section discusses in detail only those considerations arising from those factors which directly affect field fortification design and the engineer effort (by engineer or nonengineer units) required to provide adequate protection. The factors involved are—

(1) The proportion of a given type of supply or activity which a command can afford to lose to one nuclear weapon. This involves stockage and reserve levels, resupply capabilities, and other similar considerations.

(2) The maximum size of weapon which the enemy can deliver upon the administrative support installations of a command.

(3) The number of separate locations for installations which can be utilized considering the available area, facilities, and transportation network, the operating efficiency of installations, local security problems, and other types of units in the area.

(4) The size of the total area over which a given installation can operate adequately, and the amount of this total area which must be physically occupied.

c. Specific Requirements. From these general factors are drawn the following specific

requirements for each installation, affecting field fortifications design.

(1) The proportion of the supplies or activities in a specific installation which is the maximum that one nuclear burst can be permitted to destroy.

(2) The distance which must be maintained between those portions of the installation that are not to be destroyed by a single nuclear burst for different levels of field fortifications construction.

(3) The total area through which the ininstallation can be dispersed, the amount of this area which must be physically occupied, and the facilities within the area which must be utilized.

d. Protective Layout of Installations. To provide maximum protection with minimum effort, utilizing the factors just described, the layout of an installation must be planned in conjunction with the fortifications and shelters designed to provide the desired level of protection. Layouts can be planned for any specific size of nuclear weapon, degree of physical protection, and existing available area so as to provide that a given proportion of any type of supply facilities, or personnel, will survive the burst of one nuclear weapon. This layout may often resemble or be coordinated with the superimposition of units discussed in paragraphs 13*d*, 18*e*, and 19*f*. In considering the layout of installations, four different types of installations will be considered.

(1) *Undispersed.* These are installations which are small enough or of such a nature that dispersal of the components of the installation into subinstallation areas is not desirable, even though it is recognized that the entire installation may be lost to one nuclear weapon. See details in paragraph 16.

(2) *Linearly dispersed.* These are installations which are of a nature facilitating linear layout and which contain supplies or facilities which the command cannot afford to lose in their entirety to one nuclear burst. Linearly dispersed installations are long narrow installations (usually along road nets) which can be long enough for the combination of layout and physical protection to permit one or more portions of the installation to remain intact when a nuclear weapon destroys some other portion of the installation (para 17).

(3) *Point dispersed.* These are installations which can operate in more than one local area in the same vicinity, which contain supplies or facilities which the command cannot afford to lose in their entirety to one nuclear burst, and which have small operating area requirements. Such an installation consists of two or more small, subinstallations at points separated from each other by distances dictated by the considerations discussed in paragraph 18.

(4) *Area dispersed.* These are installations or groups of installations which can operate in more than one local area in the same vicinity. They contain supplies or facilities which the command cannot afford to lose in their entirety to one nuclear burst, and have fairly large operating area requirements. Such an installation consists of two or more subinstallations in areas separated from each other by distances dictated by the considerations discussed in paragraph 19.

16. Undispersed Installations

The primary requirement for protection of an undispersed installation as described in paragraph 15*d*(1) is protection from fallout, except when the protection is intended to be of such a high level as to permit a significant probability that an enemy nuclear weapon aimed at the installation will miss far enough due to normal delivery error to leave the installation intact.

a. Protection Against Fallout. The essential requirement for protection against fallout is protection of personnel, but steps should be taken to facilitate ready decontamination of supplies and equipment, when radiation levels have decreased enough to allow this. Personnel may be protected by field fortifications or by more elaborate structures, requiring greater

engineer effort. Normally, available time, supplies, and engineer effort will dictate use of field fortifications described in this section. The fallout transmission factors (para 39) with each fortification provide information on fallout protection. Field fortifications provide limited protection against fallout, reducing the dose by 10 to 100 normally. If more shelter is desired, from within which operations may be continued while radiation intensities remain high, special design and engineer effort will normally be required (ch. 7).

b. High Levels of Protection. For certain critical installations, especially those prepared before a war, a very high level of protection may be desired, so that these installations will provide a chance of survival from a large nuclear burst. Such shelters often involve use of existing deep underground cavities.

17. Linearly Dispersed Installations

One of the best ways to provide administrative support installations with protection from nuclear attacks is to lay out the installations generally in a straight line, paralleling a road

ver,
some ad-
because of
the installa-

Physical Pro-
s of linearly
ed in para-
proportion of
attack by a
ze. For com-
materiel sub-
weapons of megaton yield, the distances required between portions of an installation to insure that no more than one portion will be destroyed by one nuclear weapon are often prohibitive. Proper use of field fortifications and shelters can greatly reduce these distances. In addition, location of existing facilities may govern the location of portions of the installation, preventing the use of arbitrary separation distances. In laying out a linear installation, the level of shelter provided can be varied with the distance between line components of the installation to insure that one of these components will survive a nuclear burst of given size; or the reverse process can be followed in which the distance between like components of the installation can be varied according to the shelter provided to insure the survival of one component of the installation from an attack by the given size nuclear burst. The interrelationship of the shelter and separation distance is illustrated in figure 4. In this illustration a linearly dispersed installation is shown in which ⅔ of the materiel and personnel are to survive a 1-megaton burst. Without any shelters or fortifications the installation must be 27 kilometers long (17 miles) to fulfill the requirements. Using fairly simple personnel shelters it can be reduced to a length of 16 kilometers (10 miles). Using better personnel shelters and open trenches to protect materiel, it can be reduced to 13 kilometers (8 miles) and still provide for ⅔ survival from a 1-megaton burst. In this figure, the road AB is the axis supply point. Subinstallations are indicated by the letters X, Y, and Z. An airstrip is located at C. The letters A, D, F, and B indicate a bypass road, with secondary roads going to ...nd G.

b. Fallout Protection. Normally, shelters that protect personnel from initial effects will also provide adequate fallout protection. The discussion in paragraph 16*a* on fallout protection for undispersed installations applies here also.

c. Concealment. Certain characteristics of a linear installation facilitate its concealment. If the installation is disposed along a large and active road net, normal activity on the road will distract attention from the activity of the installation and lessen the chances of revealing its position and nature.

18. Point Dispersed Installations

a. Description. An alternative to the linear installation layout is dispersion of subinstallations about a central point. For small installations, this takes the form of dispersal of points at a few chosen locations. One advantage of such dispersion is that all the dispersed subinstallations can use common facilities at the center.

b. Coordination of Layout and Physical Protection.

(1) For layout of a small installation in several dispersed points, there should be chosen, based on enemy capabilities, a size of weapon from which a definite proportion of supplies and personnel must be protected. The critical effect

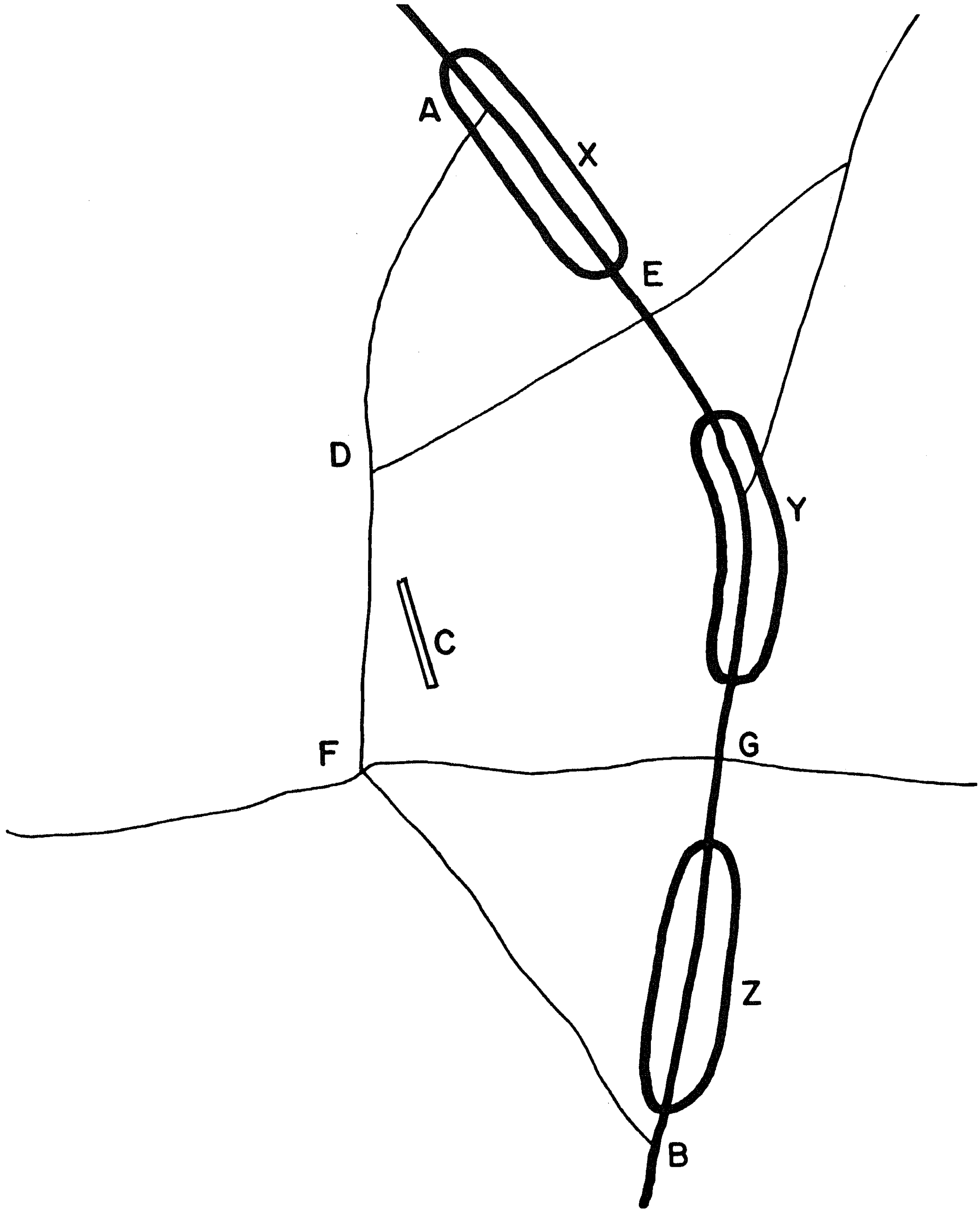


Figure 4. Linearly dispersed installation layout.

radius of this design weapon is matched against the critical item to be protected, and the points are dispersed so that an adequate distance will separate each point from the next. The effect of field fortifications in reducing this distance, and the corresponding effort involved for various levels of protection, can be calculated, using figure 5. The installation in figure 5 is not large enough for dispersion to the extent required for a megaton weapon and still accomplish its mission effectively. Therefore, the plan is to protect it against a large tactical weapon, such as one of 200-KT yield. Simple protective measures will be taken which may include shallow trenches and revetments for certain supplies and equipment, small cover shelters for personnel, and the use of foxholes. Three points (A, B, and C) are chosen for development. They will be 4,000 meters (2.5 miles) apart to insure that at least two of the points

supplies are
lters and sup-
ast resistance
grams/sq. cm.)
pected, and so that the personnel in their shelters have radiation protection comparable to 25 psi blast resistance, the distance can be further reduced to 3 kilometers (1.85 miles).

c. Fallout Protection. Normally shelters that protect personnel against initial effects will also provide adequate fallout protection. Refer to paragraph 19*a* which applies to any administrative support installation.

d. Concealment. The small area physically occupied by the few points constituting the point dispersed installation makes the problem of concealment relatively simple. The points may be shifted to the most easily concealed sites, as long as the required minimum distance between points is maintained and the sites selected allow efficient operation.

e. Superimposition. The point dispersed installation, because of the relatively small area physically occupied, is readily adaptable to having other units superimposed upon its overall area. This facilitates security but adds to the problem of concealment of the entire area. The area as a whole will become a more lucrative nuclear target as more units are added to it. But if each unit properly disposes itself and digs in appropriately, no one unit capable of dispersion should be made ineffective by one nuclear burst.

19. Area Dispersed Installations

a. Description. Some installations have so many components, or must physically occupy so large an area, that these components cannot be efficiently dispersed either linearly or as a separated group of points. In such a case, the various components may be grouped as subinstallations located in a wide band about a central point (city M). Such a pattern is more suitable for a rear area complex whose parts utilize common facilities than it is for smaller

bat area installations which do not physically occupy a large area. The band of subinstallations resembles a doughnut whose inner area is large enough to include the damaging effects of a specified size weapon. The outer radius is sufficiently larger than the inner radius to provide operating space for the equipment units of the installation (fig. 6). Intelligence indicates enemy delivery systems have a CEP (circular error probable) permitting them to have a 90 percent probability of coming within 600 meters (0.37 miles) of the aiming point. This gives a buffer distance of 1,100 meters (0.6 miles) to add to the minimum safe distance in determining how far from the center of M it is desirable to put different subinstallations. If troops in the open should be 10,400 meters (6.5 miles) from a 5-MT burst; in foxholes, 5,800 meters (3.6 miles); and in shelters, 4,300 meters (2.7 miles); then this data in figure 6 would show 11,500 meters (7.15 miles), 6,900 meters (4.28 miles), and 5,400 meters (3.35 miles), respectively. The use of trenches, shelters, and emplacements can reduce both the inner radius and the outer radius, and by thus decreasing the overall area can improve intrainstallation coordination.

b. Layout.

(1) The activities of the installation should be dispersed throughout the operating zone. The center of each subinstallation (indicated by W, X, Y, and Z) should be separated sufficiently from the next to insure survival of the required proportion

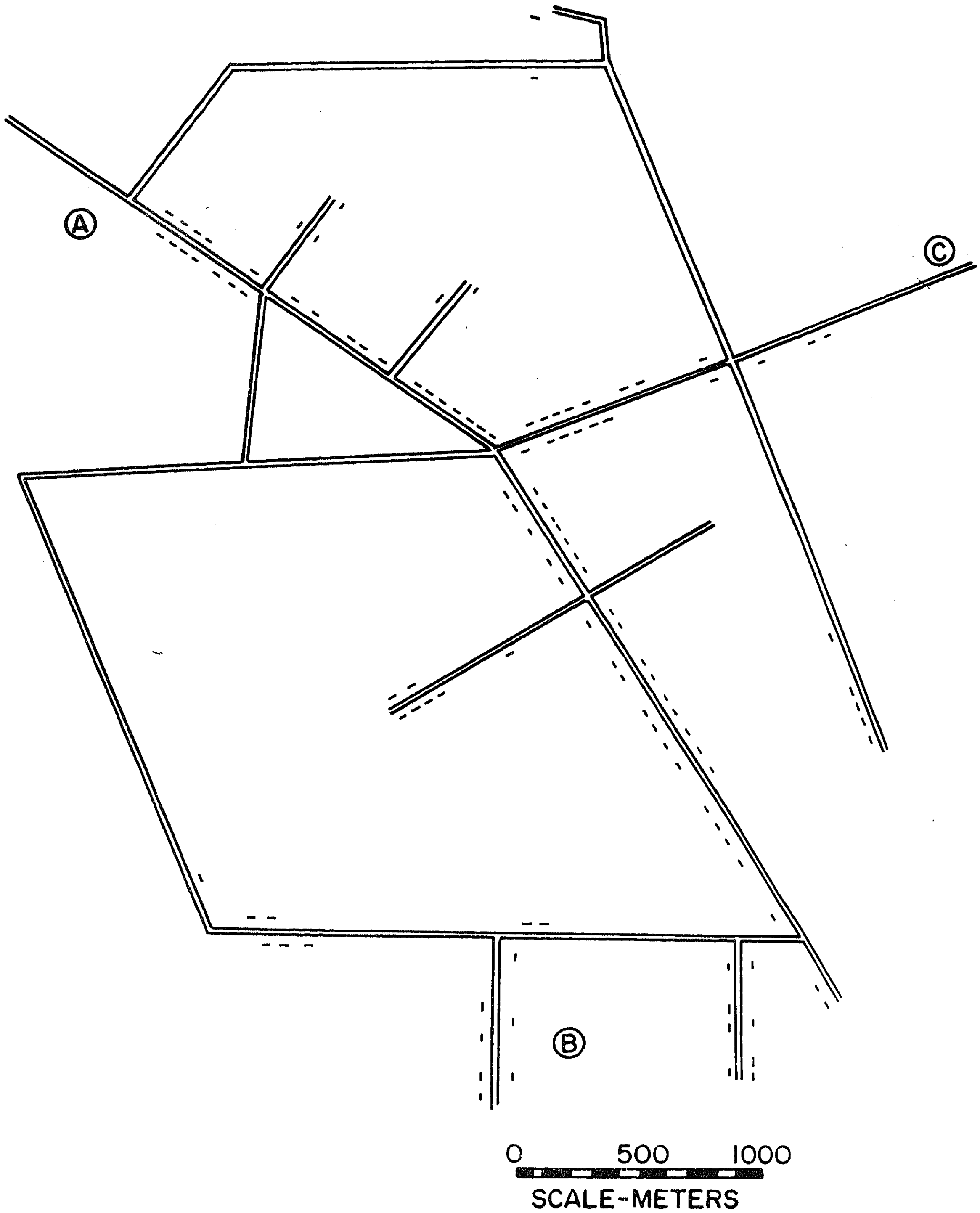


Figure 5. Point dispersed installation layout.

of the total installation after a burst of a specified weapon on the worst possible spot. Like activities must be separated by a distance equal to twice the radius of the critical effect. Activities which are most vulnerable should be placed at the outer edge of the operating zone.

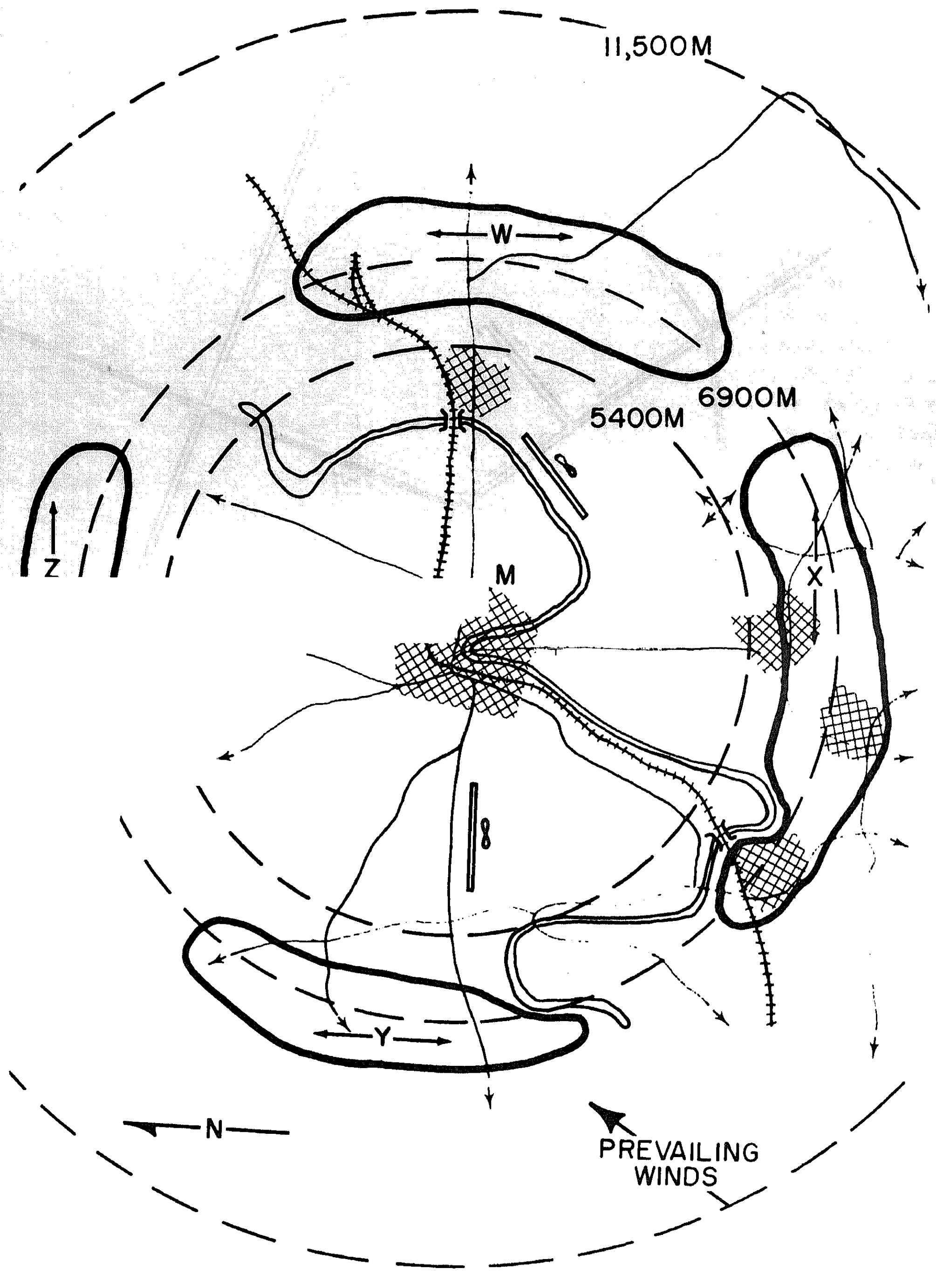


Figure 6. Area dispersed installation layout.

(2) The central area of the "doughnut" may be used to facilitate intrainstallation coordination over its road network, to store surplus or salvage items, and to locate those activities whose survival is less essential, or which have a particularly low vulnerability to weapons effects.

(3) Since like activities must be separated, if possible, it follows that each subinstallation will contain a variety of activities. Thus a maintenance company may be divided into three widely separated platoons, if it can operate when so divided. The accompanying loss in efficiency must be weighed against the protection gained by dispersal.

c. Physical Protection. In such an installation, the various supplies and equipment and the personnel will be affected differently by different levels of weapons effects. Field fortifications should be designed to bring the more vulnerable items up to the level of hardness of the more resistant items. Critical items should receive priority for protection. The extent to which an activity can be hardened by shelters and emplacements will directly affect where the activity should be placed in the installation. Digging in an activity which requires a large operating area may require considerable effort and reduce the operating efficiency, but this digging in will allow a decrease in distance between components, which may offset the loss in efficiency. Since a rear area installation will normally stay in place for a comparatively long time, the planned layout should include the use of field fortifications throughout the installation.

d. Fallout. An area dispersed installation is large enough so that protection from fallout can depend on location of the various activities within the whole installation. The direction of the prevailing winds can be determined, and if a nuclear burst is most probable in the center of the installation, those activities which would be most impeded by fallout should be placed upwind of the center.

e. Concealment. The large amount of area physically occupied by some logistic installations makes concealment difficult. On the other hand, the large amount of area available in the operating band of an area dispersed installation may offer considerable opportunity for selecting individual areas which possess considerable concealment potential. In selecting such areas, the possibilities of tree blowdown and fires must be kept in mind.

f. Superimposition. Superimposition of activities and units is a prerequisite for an area dispersed installation. Each subinstallation contains a variety of dissimilar units which share common facilities and security. Without superimposition, the requirements for area would be impossible to fulfill.

CHAPTER 2

EFFECTS OF NUCLEAR WEAPONS

Section I. FORMS OF ENERGY IN NUCLEAR DETONATION

20. Introduction

The effects of nuclear weapons and protective measures in the field against those effects are discussed in paragraphs 6 through 10 above. A nuclear explosion (blast) can be many thousands (or millions) of times more powerful than the explosion of even the largest conventional weapon.

21. Forms of Energy

In addition to the blast, nuclear explosion is accomplished by highly penetrating and harmful invisible rays (initial nuclear radiation). A fairly large proportion of the energy in a nuclear explosion is emitted in the form of light and heat (thermal radiation). Finally, the substances remaining after a nuclear explosion are radioactive and emit similar radiations over an extended period of time (residual radiation).

Section II. BLAST

part
...sion of
of blast or
... produced by the
...ds so rapidly that a
...ompressed air is formed
... the fireball reaches about
...maximum size, its rate of expan-
...es and the blast wave breaks away
... the fireball and continues outward at a speed greater than that of sound. The major characteristic of the blast wave is that the pressure is highest at the leading edge of the wave (referred to as the shock front) and the pressure behind the front falls off in a regular manner. After a short time, when the shock front has traveled a certain distance from the fireball, the pressure behind the front drops below that of the surrounding atmosphere and a "negative phase" is formed. The front of the blast wave weakens as it progresses outward and its velocity decreases until it reaches the speed of sound. Thereafter it continues at the speed of sound.

b. Overpressure. The blast effect from a nuclear explosion develops an overpressure (excess of pressure over the 14.7 psi (1.03 kilograms/sq cm) atmospheric pressure). Some structures are damaged by an overpressure as low as one-half psi (35 gr/sq cm). Overpressure varies according to time and distance from ground zero (GZ). The maximum value at the blast wave front (or shock front) is *peak overpressure.* The main characteristic of this wave is that the pressure rises sharply at the moving front and falls off toward the interior area of the explosion. Just before the breakaway (which occurs about 0.015 second after the detonation of a 20-KT weapon), pressures at the shock front are about twice as high as those in the interior of the fireball.

c. Underpressure. The overpressure at the shock front decreases as it moves away from GZ, and the pressure behind the front falls off until it eventually drops below atmospheric pressure so that an underpressure exists. This negative phase (which is longer than the positive phase) produces a partial vacuum, causing

the air to be sucked back instead of being pushed away.

23. Dynamic Pressure

a. Overpressure and Dynamic Pressure. Another force for destruction of equal importance with peak overpressure is dynamic pressure. For many buildings, the extent of blast damage depends largely on the drag force of the winds accompanying the blast wave. This drag force is influenced by the shape and size of the structure, but it is generally dependent upon the peak value of the dynamic pressure and its duration at a given location. Dynamic pressure is proportional to the square of the wind velocity and to the density of the air behind the shock front. For very strong shocks, the dynamic pressure is greater than the overpressure, whereas for weaker shocks, the reverse is true. Table II indicates the corresponding values of peak overpressure, peak dynamic pressure, and maximum blast wind velocities for an ideal shock front at sea level. At any given point, the dynamic pressure changes with time in a manner similar to the change in overpressure as the shock front passes that point, but the rate of pressure decrease is usually different. Figure 7 shows this variation in the course of the first 2 seconds or so following the arrival of the shock front. In this illustration, the peak overpressure is about 5 pounds per square inch (352 grams/sq cm); the peak dynamic pressure is close to 0.7 pounds per square inch (49 grams/sq cm). At different values of the peak overpressure the relative positions of the two curves will be different, in accordance with the data in table II. Figure 7 shows that when the shock front reaches a given point (arrival time), both the overpressure and the dynamic pressure increase almost immediately from zero to their maximum values and then decrease. Dynamic pressure (and wind velocity) will fall to zero somewhat later than the overpressure because of the momentum of the air in motion, but this difference is not significant when estimating damage. During the negative (or underpressure) phase of the blast wave (para 22*c*), the dynamic pressure is very small and acts in the opposite direction. The damage sustained during this negative phase is generally light as compared to the positive phase.

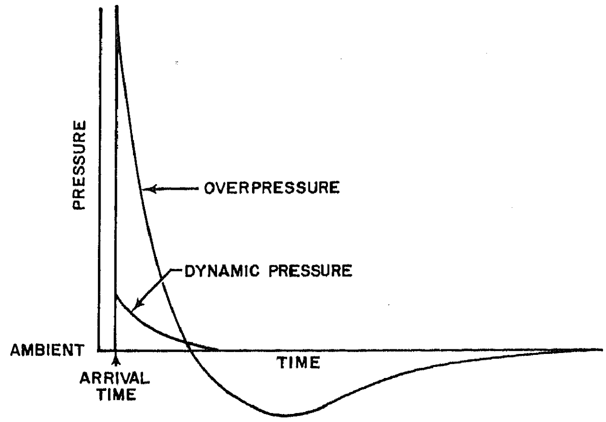


Figure 7. Variation of overpressure and dynamic pressure with time at a fixed location in the low-pressure region.

Table II. Overpressure, Dynamic Pressure, and Wind Velocity in Air at Sea Level for an Ideal Shock Front

Peak Overpressure		Peak Dynamic Pressure		Maximum Wind Velocity	
Lbs/sq in	Kilograms/sq cm	Lbs/sq in	Kilograms/sq cm	Miles/hr	Kilometers/hr
200	14.06	330	23.20	2,080	3,347
150	10.54	223	15.68	1,778	2,861
100	7.03	123	8.65	1,414	2,275
72	5.06	80	5.62	1,170	1,883
50	3.51	40	2.81	940	1,512
30	2.11	16	1.12	670	1,078
20	1.40	8	0.56	470	756
10	0.70	2	0.14	290	467
5	0.35	0.7	0.049	160	257
2	0.14	0.1	0.007	70	113

b. Arrival Time and Duration.

(1) A definite time interval is required for the blast wave to move out from the explosion center to any particular location. This time interval (arrival time) varies with the distance and the energy yield of the nuclear weapon. To take a specific example, the arrival time at 1 mile (1.6 kilometers) from a 1-megaton burst would be about 4 seconds. Initially, the velocity of the shock front is many times the speed of sound, but as the blast wave progresses outward, it slows as the pres-

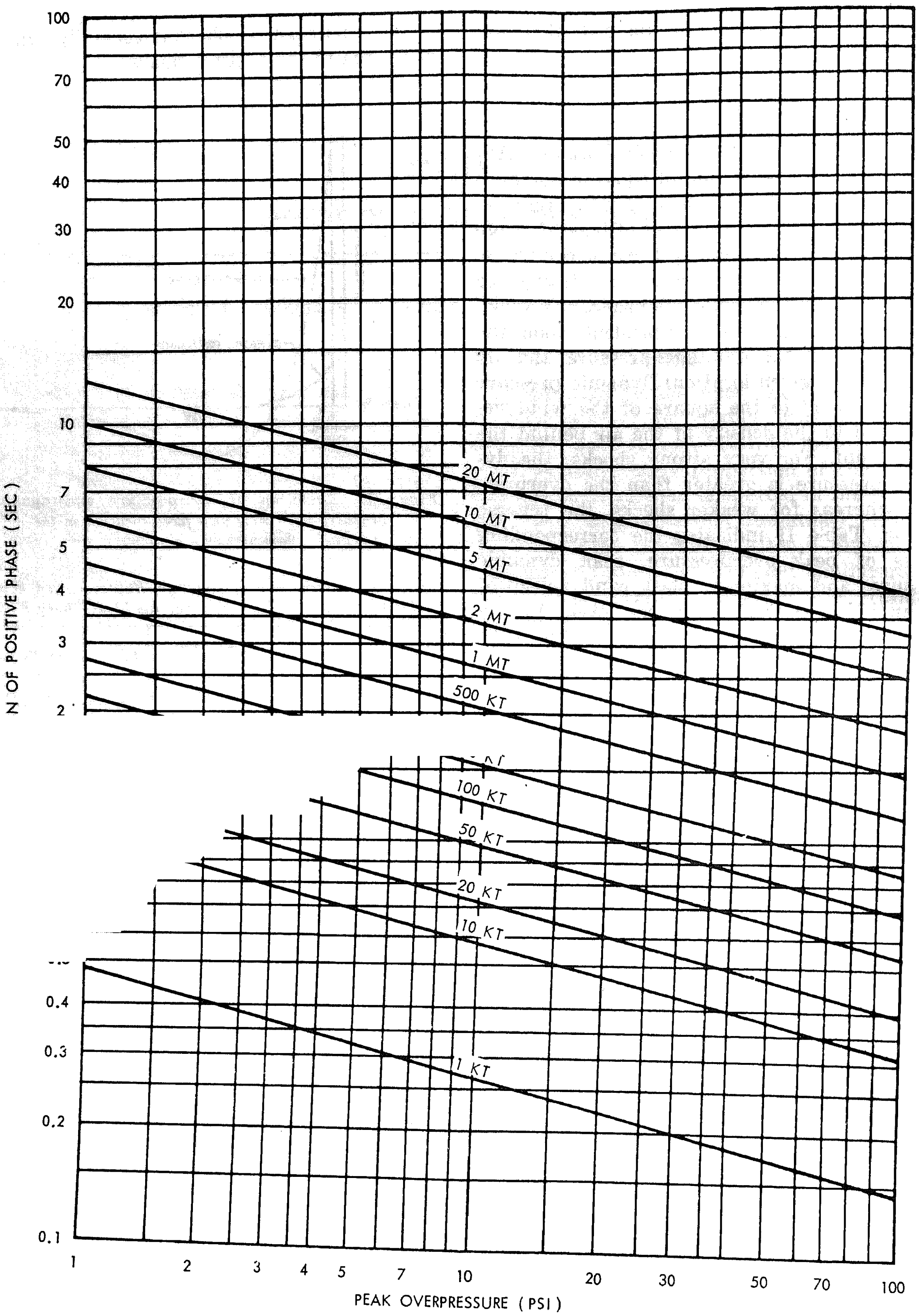


*Figure 8. Duration of positive phase—**typical airburst.***

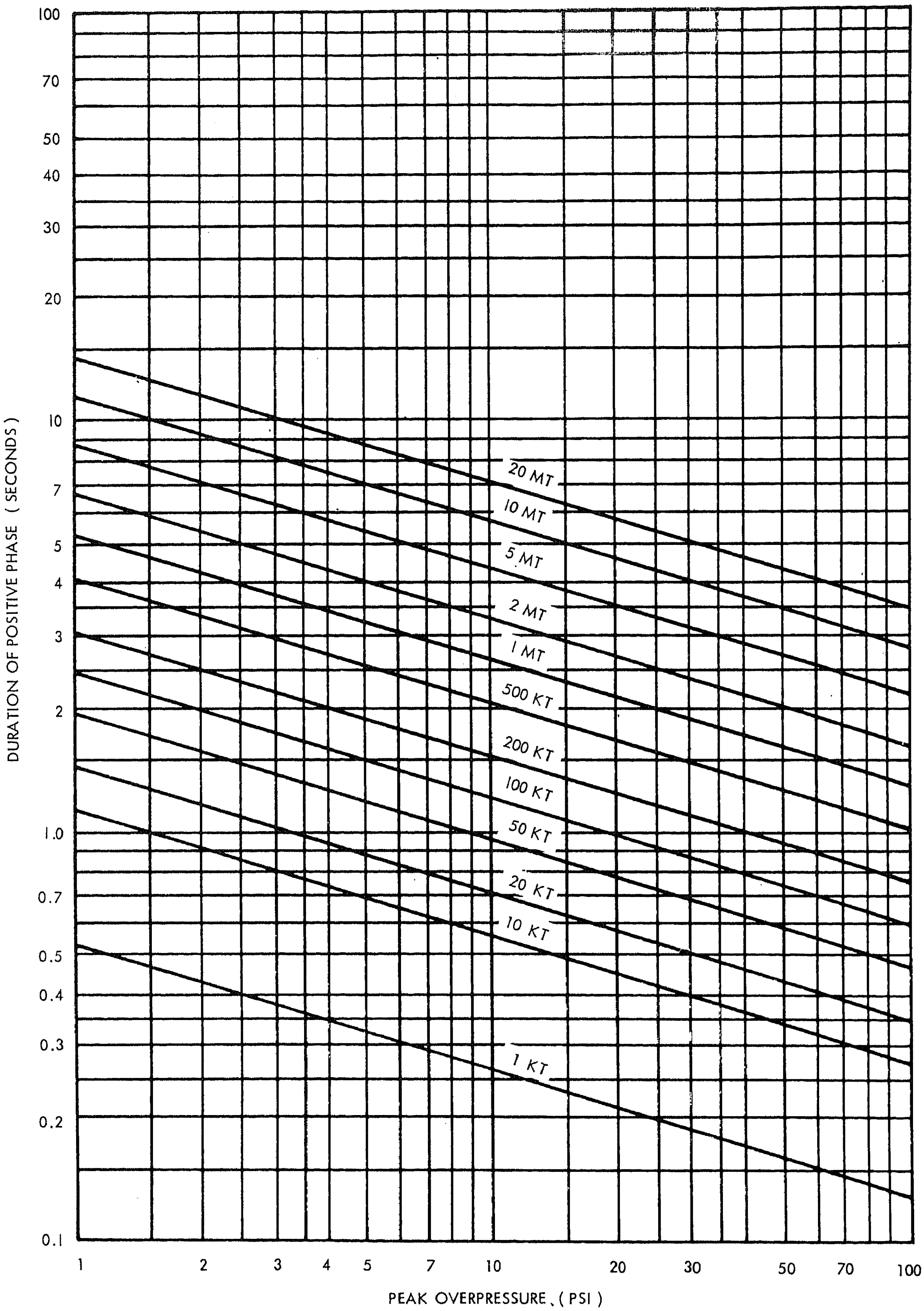


*Figure 9. Duration of positive phase—**typical surface burst.***

sure at the front weakens. At long ranges, the blast wave becomes essentially a sound wave and reaches sound velocity.

(2) Duration of the blast wave at a particular location also depends on the distance and the energy of the explosion. The positive phase duration is shortest at close ranges and increases at longer ranges. At 1 mile (1.6 kilometers) from a 1-megaton explosion the duration of the positive phase is about 2 seconds. See figures 8 and 9 for values of the duration of the positive phase.

(3) The wind velocity lowers to zero after the end of the overpressure positive phase (*a* above). Although the duration of the positive dynamic pressure phase may exceed that of the positive overpressure phase by varying amounts, depending on the pressure levels, the difference is so slight that the two phases may be taken as essentially the same.

...vnen ...land ...a single ...ecause the ...ously. Near ...essure will be ...eak overpressure

...eflected wave travels through ...heated and compressed by the passage of the incident wave, making it possible for the reflected wave front to move faster than the incident wave and, under certain conditions, to overtake it. The two wave fronts then fuse to produce a single front. This wave interaction is called *Mach,* or *irregular,* reflection. The region where the two waves merge is called the Mach, or irregular, region.

(2) The blast wave travels in a horizontal direction at the surface, and the transient winds are nearly parallel to the ground. This action directs the blast forces on the above-ground structures in the Mach region nearly horizontally. Vertical surfaces therefore are loaded more intensely than horizontal surfaces.

c. Height of Burst and Blast Damage. The height of burst and energy yield of a nuclear weapon influence the damage effects at the surface. If the height of explosion is decreased or the energy yield is increased, the Mach reflection will begin nearer to GZ and the overpressure at the surface nearer GZ will become larger. A contact surface burst causes the highest possible overpressures near GZ.

d. Contact Surface Burst. The general airblast effects of a contact surface burst are different from those of an airburst. In the surface burst the shock front is hemispherical in form. There is no region of regular reflection, and all objects on the surface, even those close to GZ, undergo airblast similar to that in the Mach region. It may be assumed that the shock ...ont is vertical for most structures, with over...essure and dynamic pressure decaying at different rates behind the shock front (figs. 10 and 11). The transient winds behind the wave front near the surface are essentially horizontal.

e. Subsurface Burst. When a weapon is burst underground there is no Mach effect and no apparent reinforcement of the original blast wave. Pressures of subsurface bursts are lower than those produced by air and surface bursts.

25. Blast Loading on Structures

a. Meaning of Loading and Response.

(1) The behavior of an object or structure exposed to the blast wave from a nuclear explosion may be considered under two main headings. The first is called the *loading,* that is, the forces which result from the action of the blast pressure. The second is the *response* or distortion of the structure due to the particular loading. As a general rule, responses may be considered as damage because sufficient permanent distortion will impair the

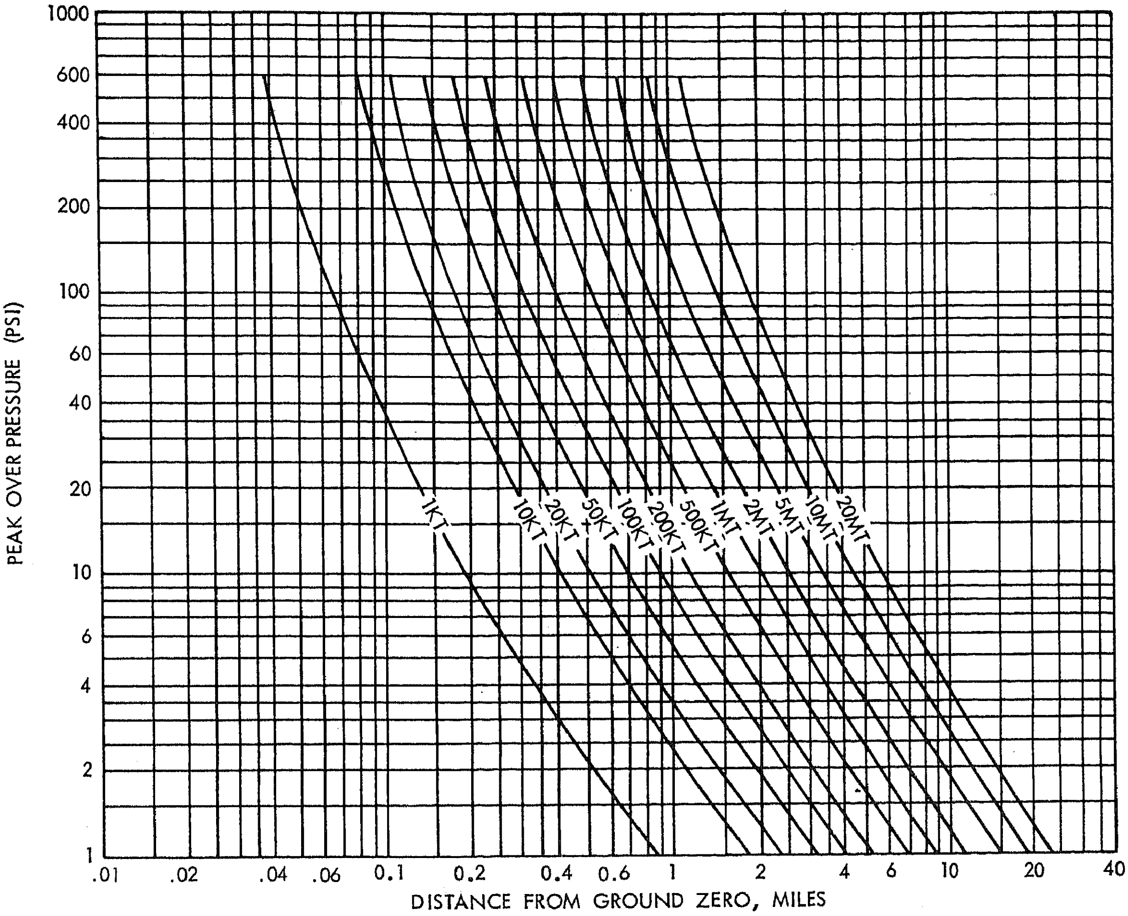


*Figure 10. Peak overpressure—**surface burst***

usefulness of a structure. Damage may also come from a movable object striking another object which is fixed. This is indirect damage and the extent depends upon circumstances.

(2) Direct damage to a structure from airblast can take various forms. A blast may bend structural steel frames, collapse roofs, shatter panels, and break windows. For an airburst, the direction of the incident blast wave is toward the ground at ground zero (GZ). In the reflection region, the force of the blast will also have a considerable downward component (before the reflected wave passes) because of the reflected buildup on the horizontal surfaces. Therefore, along with the horizontal loading, as seen in the Mach region, there will be an initial downward force, causing crushing toward the ground.

b. Diffraction Loading. As the front of an airblast wave (or shock front) strikes the face of a building, reflection occurs, which builds up overpressure rapidly to many times that in the incident wave front. The amount of this pressure depends, among other things, on the peak overpressure of the incident blast wave and the angle between the direction of the wave motion and the face of the building. As the wave front moves forward, the reflected overpressure on the face drops rapidly to that produced by the blast wave without reflection (often called side-on overpressure), plus an added drag force from the wing (dynamic pressure). While this is taking place, the air pressure wave bends, or "diffracts," around

the structure, eventually engulfing the structure, and about the same pressure is exerted on the sidewalls and roof. Meanwhile the front wall is still under the wind pressure although the back wall is shielded from it. The force known as *diffraction loading* comes into this picture when the pressure between the front and back faces is at its maximum value, which is when the blast wave has not yet completely surrounded the structure. It is called diffraction loading because it operates while the blast wave is being diffracted around the structure.

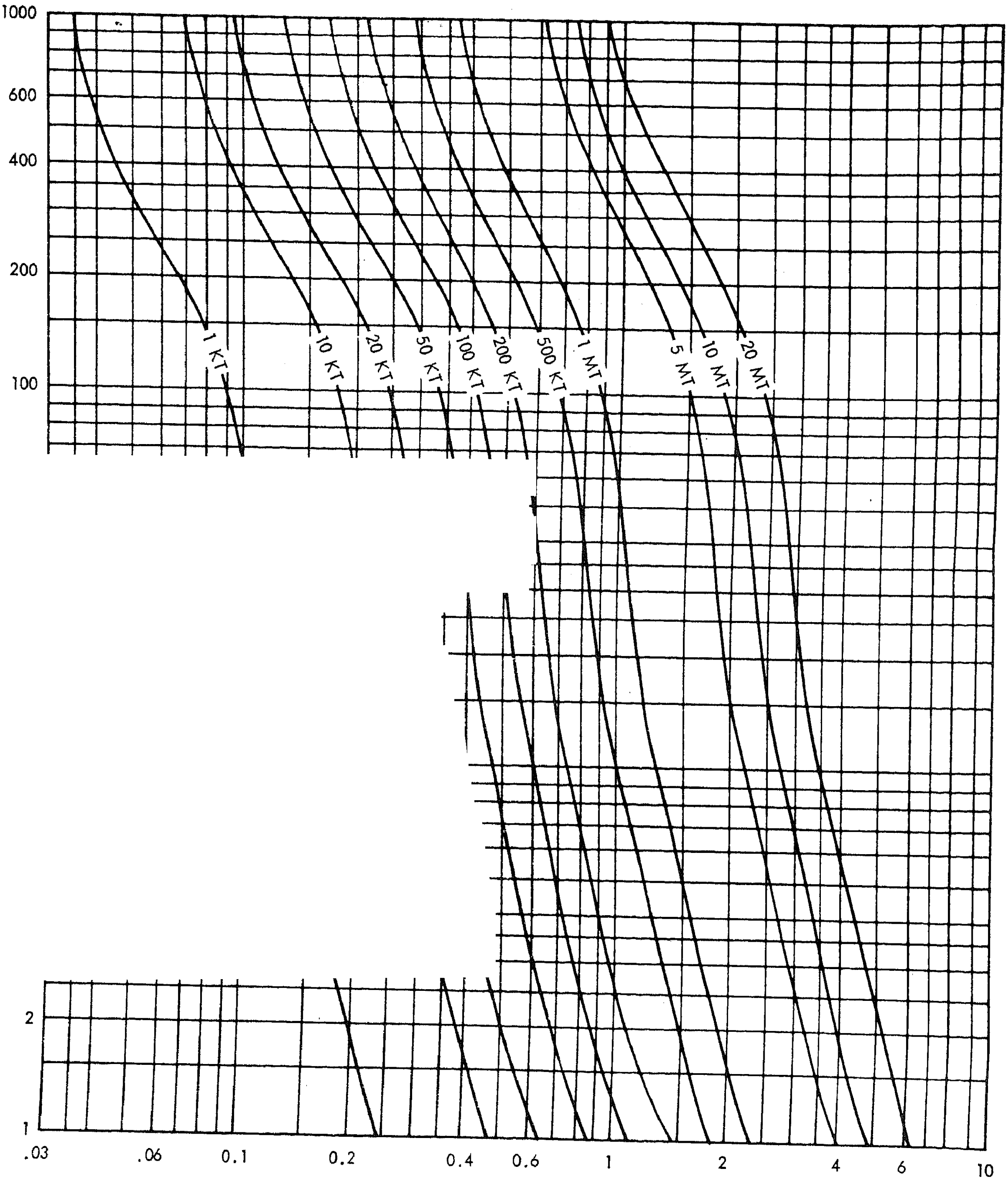


*Figure 11. Dynamic pressure—**surface burst***

When the blast wave has engulfed the structure, the pressure differential is small and the loading is due almost entirely to the drag pressure exerted on the front face. For a structure to be built aboveground, refer to DA Pam 39–3.

c. Drag (Dynamic Pressure) Loading.

(1) For the whole duration of the overpressure positive phase, plus a short time thereafter, a structure is subjected to dynamic pressure loading, or drag loading, caused by the transient winds behind the blast wave front. In nonideal conditions, a dynamic pressure loading of varying strength may exist before the maximum overpressure (diffraction) loading. Drag loading, especially in the Mach region, is also equivalent to a lateral force acting upon the structure exposed to the blast.

(2) Because of the blast wave and its reflection (table II), the dynamic pressures at the face of a building (except at high blast pressures) are much less than the peak overpressures. Yet the drag loading on a structure may persist for a relatively long time, compared to the diffraction loading. The latter is effective for only a small fraction of a second, while the positive phase for the same weapon (1-megaton) lasts about 2 seconds at a distance of 1 mile (1.6 kilometers).

(3) The effect of this duration of drag loading on structures makes up an important difference between nuclear and conventional detonations. This is because the blast wave is of much shorter duration (a few hundredths of a second) for a high-explosive weapon. Because nuclear detonations have a longer duration positive phase, increasing with higher yields, than do conventional high explosives, structures will be subjected to maximum loadings for correspondingly longer time periods during which structural response can take effect. Thus the longer pressure pulse of higher yield nuclear weapons will produce greater damage or destruction from a given peak overpressure than might otherwise be expected.

d. Reflected Pressures. As the blast wave strikes the front face of a rectangular structure, a reflection occurs which produces reflected pressures that may be from two to eight times as great as the incident overpressure. The blast wave then diffracts around the structure, exerting pressures on the sides and top of the object, and finally on its rear face. This engulfs the structure in the high pressure of the blast wave. This pressure decays with time, eventually returning to ambient conditions. Because the reflected pressure on the front face is greater than the pressure in the blast wave above and to the sides, the reflected pressure cannot be maintained and soon decays to a *stagnation pressure*, which equals the incident overpressure plus the dynamic (drag) pressure. The decay time is roughly that required for a wave to sweep from the edges of the front face to the center of this face and back to the edges. This phenomenon is shown in figure 12, which depicts the changing relationships between angles of incidence and reflected overpressure ratios. Reflected overpressure ratios are highest for side-on overpressures of 30 psi (2 kilograms/sq cm) and over, where there is a vertical face. They decrease only slightly for angles of incidence between 0° and 37°, approximately, beyond which they decrease sharply at angles of incidence up to 45° and 50° and less sharply thereafter. Curiously, there is a crossover point around the 25 psi (1.76 kilograms/sq cm)level, below which peak reflected overpressure ratios are produced at angles of incidence between 40°, and 67° for side-on overpressures of 25 psi and 2 psi (1.76 kilograms and 141 grams/sq cm), respectively. This phenomenon must be considered in connection with blast door design and the slope to be given earth cover over semiburied structures.

26. Structural Characteristics and Air Blast Loading

a. In anlyzing the response to blast loading, structures should be considered in two categories. Although all buildings are affected by both types of pressure, some structures are

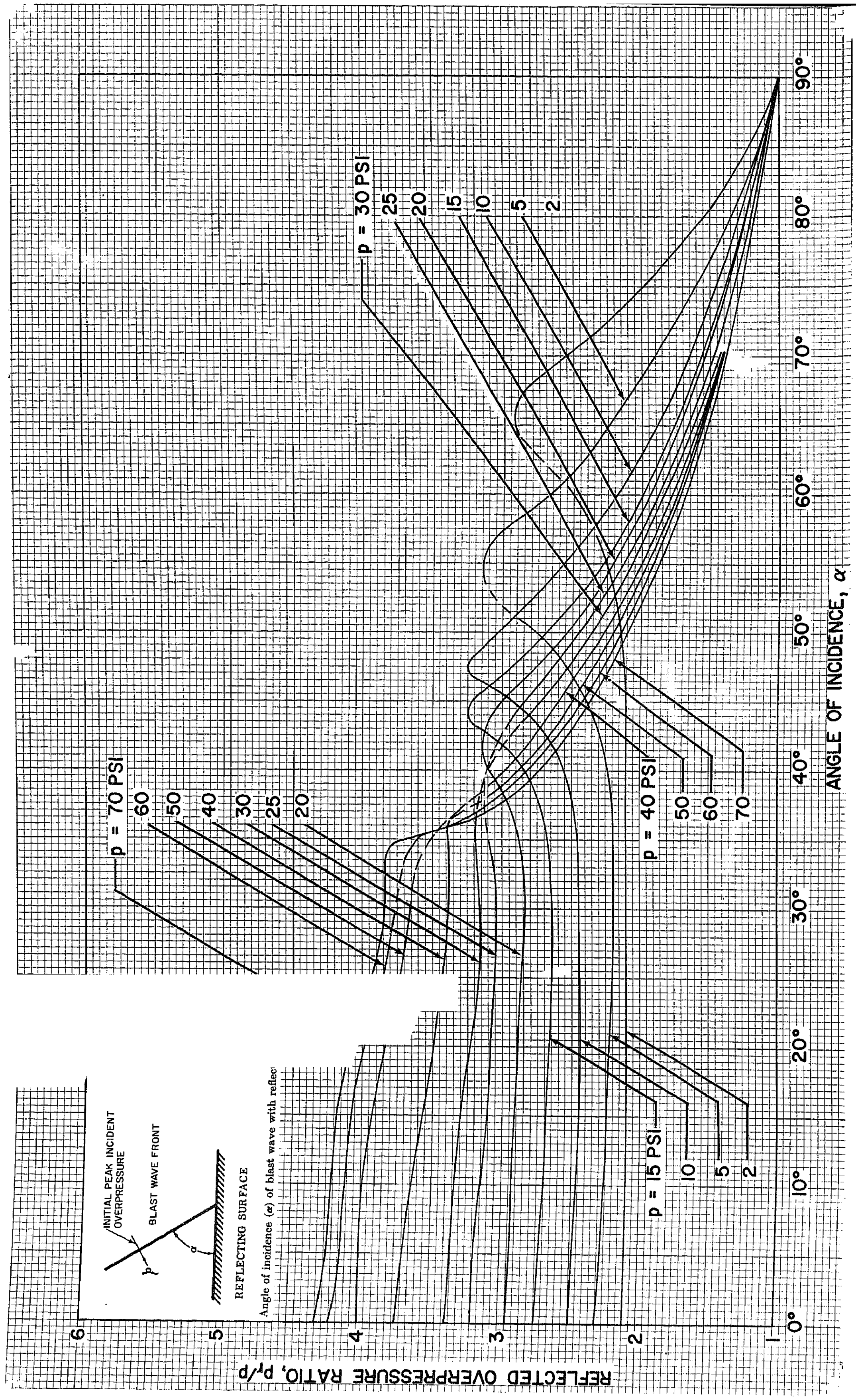


Figure 12. Reflected overpressure ratio as function of angle of incidence for various side-on overpressures.

primarily damaged by pressure during the diffraction phase and others during the drag phase. The importance of each type of loading in causing damage depends upon the type of structure and the characteristics of the blast wave.

b. The range (or area) within which a particular type of structural damage is experienced depends upon the weapon yield and the type and height of burst. There are scaling rules that relate a weapon yield to the distance at which a given peak overpressure is attained in the blast wave. For structures damaged primarily during the diffraction phase, where peak overpressure is the important factor in determining response to blast, the effect of a yield on the range (or area) within which a particular type of damage is sustained can be readily calculated.

27. Blast Loading on Aboveground Structures

a. Diffraction and Drag Loading. Table III is concerned with structures of the types affected primarily by the blast wave during the diffraction phase, where peak overpressure largely determines the damage. Table IV gives data for structures primarily affected by drag (or wind) loading, so both the peak dynamic pressure and the duration of the positive phase of the blast wave are important. The damage ranges for structures of various types from weapons of different yields are given in figure 13.

Table III. Damage to Types of Structures Primarily Affected by Blast Wave Overpressure During the Diffraction Phase

Description of structure	Description of damage		
	Severe	Moderate	Light
Multistory reinforced concrete building with reinforced concrete walls, blast resistant design for 30 psi (2.1 kg/sq cm) in Mach region from 1 MT, no windows.	Walls shattered, frame severely distorted, incipient collapse.	Walls breached or on the point of being so, frame distorted. Entranceways damaged, doors blown in or jammed, concrete extensively spalled.	Concrete walls and frame somewhat cracked.
Multistory reinforced concrete building with concrete walls, small window area, 3 to 8 stories.	Walls shattered, frame severely distorted, incipient collapse.	Exterior walls badly cracked, interior partitions badly cracked or blown down. Structural frame permanently distorted, extensive spalling of concrete.	Windows and doors blown in, interior partitions cracked.
Multistory wall-bearing building, brick apartment house type, up to 3 stories.	Bearing walls collapsed, resulting in total collapse of structure.	Exterior walls badly cracked, interior partitions badly cracked or blown down.	Windows and doors blown in, interior partitions cracked.
Multistory, wall-bearing building, monumental type, up to 4 stories.	Bearing walls collapsed, resulting in total collapse of structure supported by these walls; some bearing walls may be shielded enough by intervening walls so that part of the structure may receive only moderate damage.	Exterior walls facing blast badly cracked, interior partitions badly cracked, although toward far end of building damage may be reduced.	Windows and doors blown in, interior partitions cracked.
Wood frame building, house type, 1 or 2 stories.	Frame shattered so that for the most part collapsed.	Wall framing cracked, roof badly damaged, interior partitions blown down.	Windows and doors blown in, interior partitions cracked.

Table IV. Damage to Types of Structures Primarily Affected by Blast Wave Overpressure During the Drag Phase

Description of structure	Description of damage		
	Severe	Moderate	Light
Light steel frame industrial building, single story, with up to 5 tons crane capacity. Lightweight, low strength walls fail quickly.	Frame severely distorted or collapsed.	Frame suffers minor to major distortion. Cranes (if any) not operable until repairs made.	Windows and doors blown in, light siding ripped off.
Heavy steel frame industrial building, single story, with 20- to 50-ton crane capacity. Lightweight, low strength walls fail quickly.	Frame severely distorted or collapsed.	Frame somewhat distorted. Cranes not operable until repairs made.	Windows and doors blown in, light siding ripped off.
Heavy steel frame indus-	Frame severely distorted	Frame somewhat distorted. Cranes not operable until repairs made.	Windows and doors blown in, light siding ripped off.
	istorted, ie.	Frame distorted moderately, interior partitions blown down.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
	Frame severely distorted, incipient collapse.	Frame distorted moderately, interior partitions blown down.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
Multistory reinforced concrete frame office type building, 3 to 10 stories (earthquake resistant construction). Lightweight, low strength walls fail quickly.	Frame severely distorted, incipient collapse.	Frame distorted moderately, interior partitions blown down, concrete somewhat spalled.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
Multistory reinforced concrete frame office type building, 3 to 10 stories (nonearthquake resistant construction). Lightweight, low strength walls fail quickly.	Frame severely distorted, incipient collapse.	Frame distorted moderately, interior partitions blown down, concrete somewhat spalled.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
Highway truss bridges, spans 150 to 250 ft (45.7 to 76.2 m).	Total failure of lateral bracing, bridge collapsed.	Some failure of lateral bracing such that bridge capacity is reduced about 50 percent.	Capacity of bridge unchanged, some bridge components slightly distorted.

Table IV. Damage to Types of Structures Primarily Affected by Blast Wave Overpressure During the Drag Phase—Continued

Description of structure	Description of damage		
	Severe	Moderate	Light
Railroad truss bridges, spans 150 to 250 ft (45.7 to 76.2 m).	Total failure of lateral bracing, bridge collapsed.	Some failure of lateral bracing such that bridge capacity is reduced about 50 percent.	Capacity of bridge unchanged, some bridge components slightly distorted.
Highway and railroad truss bridges, spans 250 to 500 ft (76.2 to 152.4 m).	Total failure of lateral bracing, bridge collapsed.	Some failure of lateral bracing such that bridge capacity is reduced about 50 percent.	Capacity of bridge unchanged, some bridge components slightly distorted.

Illustrative example.

GIVEN: Wood frame building (type 1 in figure 13). A 1-MT weapon is burst (*a*) at the optimum height, (*b*) at the surface.

FIND: The ranges from ground zero for severe and moderate damages.

SOLUTION: (*a*) On figure 13, from point 1 (at right) draw a line to 1-MT on the severe damage scale and another to 1-MT on the moderate damage scale. The intersections of these lines with the range scale give the required solutions for the optimum burst height:

Range for severe damage
= 29,000 ft (8.84 Km)
Range for moderate damage
= 34,000 ft (10.36 Km)

(*b*) For a surface burst, the respective ranges are ¾ths those obtained above:

Range for severe damage
= 22,000 ft (6.7 Km)
Range for moderate damage
= 26,000 ft (7.9 Km)

(The values have been rounded off to two significant figures because greater precision is not warranted.)

b. Effect on Overpressure-Sensitive Elements. For certain structural elements, with short periods of vibration and small plastic deformation at failure, the conditions for failure can be expressed as a peak overpressure without consideration for the duration of the blast wave. The failure conditions for elements of this type are given in table V. Some of those elements fail in a brittle fashion, and thus there is only a small difference between the pressures that cause no damage and those that produce complete failure. The pressures are side-on blast overpressures for panels that face ground zero. For panels that are oriented so they receive no reflected pressures, the side-on pressure must be doubled.

28. Blast Loading on Buried Structures

a. General Considerations.

(1) As in conventional structural engineering, the design of a blast resistant structure involves first the selection, or conception, of a structural system which is approximately able to meet the various design conditions. In general, the preliminary design procedure against the effects of the multimegaton weapon involves proportioning the structural elements of the selected system to offer static resistance equal to or only slightly greater than the peak blast load static sure on the elements.

(2) Concerning the effects of earth shock, measurements have been made of the stresses, strains, and displacements in the earth or rock at various distances from a nuclear detonation, but only rough approximations can be given regarding underground structure loading. The reason is that the effect of a particular type of soil and

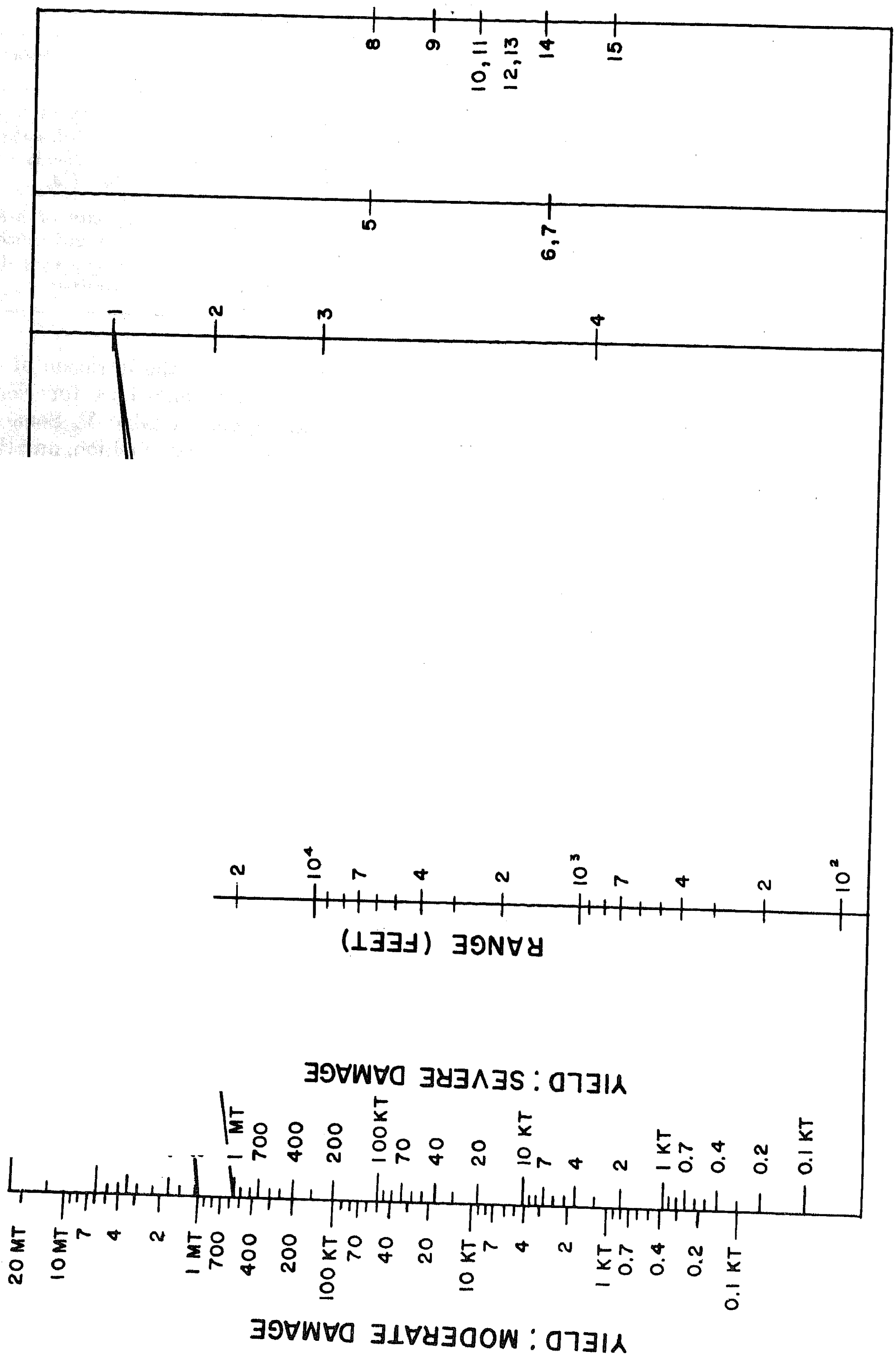


Figure 13. Damage-distance relationships for structures of various types.

1 Wood-frame building.
2 Multistory, wall-bearing buildings, brick apartment house type.
3 Multistory, wall-bearing buildings, monumental type.
4 Multistory, blast-resistant design, reinforced-concrete buildings.
5 Multistory, reinforced-concrete buildings, concrete walls, small windows.
6 Highway truss bridges, 150–250 feet (45.7–76.2 m) (blast normal to longitudinal bridge axis).
7 Multistory, reinforced-concrete frame, office type, earthquake resistant.
8 Light steel-frame industrial buildings.
9 Heavy steel-frame industrial buildings (supporting 25- to 50-ton bridge crane).
10 Heavy steel-frame industrial buildings (supporting 60- to 100-ton bridge crane).
11 Railroad truss bridges of 150 to 250 feet (blast normal to longitudinal bridge axis).
12 Multistory, reinforced-concrete frame, office type buildings.
13 Highway and railroad truss bridges, 250–400 feet (76.2–122 m) (blast normal to longitudinal bridge axis).
14 Multistory, steel-frame, office type buildings.
15 Multistory, steel-frame, office type buildings, earthquake resistant.

Ranges in figure are for optimum height of burst.
(For surface burst, use three-quarters of range obtained.)

Figure 13—Continued.

Table V. Conditions of Failure of Peak Overpressure-Sensitive Elements

Structural element	Failures	Approximate side-on blast overpressure	
		psi	gr/sq cm
Glass windows, large and small	Shattering usually, occasional frame failure	0.5–1.0	35–70
Corrugated asbestos siding	Shattering	1.0–2.0	70–141
Corrugated steel or aluminum paneling	Connection failure followed by buckling	1.0–2.0	70–141
Brick wall panel, 8 in. or 12 in. (20.3 or 30.5 cm) thick (not reinforced)	Shearing and flexure failures	7.0–8.0	492–562
Wood siding panels, standard house construction	Usually failure occurs at the main connections, allowing a whole panel to be blown in	1.0–2.0	70–141
Concrete or cinder-block wall panels, 8 in. or 12 in. (20.3 or 30.5 cm) thick (not reinforced)	Shattering of the wall	2.0–3.0	141–211

of each type and size of a detonation are not accurately known.

b. Buried Structure.

(1) A buried (underground) structure is buried completely below the surface of the ground. If it is partially above the original ground surface, it must be covered sufficiently to eliminate most of the dynamic pressure loadings at the surface of the structure. To eliminate such loadings, the earth cover must extend beyond the structure walls for distances of twice the depth of the structure. Maximum slopes must be less than 1 on 4 (25 percent). The earth cover in depth must exceed one-half the structure depth (for rectangular structures) and must average at least one-fourth the span, with a minimum cover of one-eighth the span at the crown (for arch structures).

(2) The loading on underground structures comes from direct ground- and air-induced ground shock. At 200 psi (14 kg/sq cm) peak overpressure or less, direct ground shock loading is of relatively little importance. Figure 14 depicts the air-induced ground shock front. For design purposes, there is little attenuation in the ground shock pressures to a depth of 100 feet (30.5 meters). The major factors that influence ground shock attenuation with

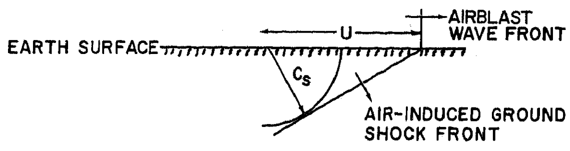


Figure 14. Air-induced ground shock preparation.

depth are moisture content of the soil, soil type, and duration of the blast wave.

(3) For design purposes, the loads on shallow buried structures should be taken as the free field ground pressures, plus the dead load of the earth cover. Shallow buried structures are defined as having a depth cover of 50 feet (15.24 meters), or less. In the following paragraphs are recommendations for the loading of shallow underground structures.

c. Rectangular Structures. For small structures, the rise time (time to reach peak overpressure) for the average load on the roof or base floor is about equal to the rise time of the airblast overpressure wave. For larger structures, the time of transit should be incorporated into the loading scheme as done for aboveground structures (para 27). Where the floor is separated from the walls of the structures, the ground shock loading on the floor is essentially zero. Sidewall loads are ¼ the airblast overpressure in dry or damp cohesionless soils; about ⅓, ½, or ¾ in unsaturated cohesive soils of stiff, medium, or soft consistency, respectively; and 100 percent of the airblast overpressures for structures in saturated soils. Again, the rise time of the average wall load is equal to the overpressure rise time. Added to this can be the vertical transit time, which is related to wall height and seismic velocity. As a whole, the structure accelerates and displaces approximately as the earth surrounding it.

d. Arch and Dome Structures. Floor loads are described in *c* above. Arch endwalls are treated as were the sidewalls of a rectangular structure. Loading on the curved arch or dome surfaces should be considered both as evenly distributed and as a load which decreases to that of sidewalls as the surface becomes vertical at the base. This consideration determines which type of load proves to be critical in the design of the structure. Also influencing the design considerations may be the orientation of the ground shock front (fig. 14), except that the rise time of the load will probably be such that the orientation is of no consequence for small- or medium-sized structures. Again, the structural accelerations and displacements will be those of the surrounding earth.

e. Underground Structures—General. For structures buried several hundred feet, the loading produced by the nuclear burst (which is primarily direct ground shock) is of no significance and only the static dead load of the cover is considered. The structures discussed here are at a range where 200 psi (14 kg/sq cm) or less peak overpressure occurs at the surface. A megaton-size surface burst directly over a deep structure can cause severe damage to estimated depths of 500 feet (152.4 meters), or more.

f. Summary. Concerning the loading of underground structures, the following points should be kept in mind.

(1) Because the density of the earth or rock cover is greater than the structure itself and because the structure may have greater or less compressibility than the earth, the earth and structure intersection are only generally known. In fact, the earth and structure form a composite structure, the properties of which cannot at this time be precisely defined—not in mathematical terms. *For example*, a flexible structure can deflect to the extent that the load is greatly reduced because the earth cover does not follow the structure but carries some of the load through arching action. This brings up the question as to how flexible the structure should be, and how long the alleviation can be maintained. If it is for only a few milliseconds, there is no benefit when

under loads that remain high for hundreds of milliseconds.

(2) The free field pressures and accelerations are known reasonably well for only a few soil types. As discussed in *a*(2) above, the effects of soil type, depth of cover, and size of nuclear burst are uncertain. To be most effective, it is generally agreed that in soil arching the depth of cover should be equal to or greater than the span of the structure. Connection to a structure must be flexible. So, even though all the exact data are still unknown, cover has been shown in practice to strengthen structures.

29. Blast Loading on Semiburied Structures

a. Purpose of Cover. A semiburied structure, though earth covered, is loaded by the dynamic pressure in addition to the overpressure of the blast wave. The structure is partially above ground level, and the earth cover is less than that discussed in paragraph 28*b* through *f*. In this case the earth cover primarily provides nuclear radiation shielding, not blast resistance, for the structure. Yet the earth cover does provide some blast shielding. Consider a one-story rectangular, arch, dome structure covered with 3 or 4 feet (0.91 or 1.22 meters) of earth which is resting at its natural slope on the sides. Such a slope presents a better aerodynamic shape, that is, a shape that has a reduced drag coefficient. The drag coefficient on the front of a 30° slope is about 0.4, whereas on the front of a rectangular shape it is about 1.0. Secondly, the earth on the rear of a structure has a buttressing effect against lateral movement. Lastly, the earth absorbs or attenuates to a limited extent the ground shock induced by the overpressure and dynamic pressure.

b. Loading. In terms of loading on the structure, only the first of the above benefits can be evaluated. The loading on the earth berm surface at the various points of front, top, and back can be computed, using the loading on aboveground structures of arch and dome shapes for computing the details. (In this case the dome and arch nonideal loading schemes can be extended to 200 psi (14 kg/sq cm). For the 200 psi (14 kg/sq cm) ideal blast wave, no reflection factor is used on the front slope because it has been shown in tests that the short peaked reflected pressure does not propagate through the earth berm to the structure.) The load as computed is transmitted without attenuation through the earh cover to the various surfaces of the structure.

Section III. INITIAL RADIATION

30. Nature of Nuclear Radiation

a. Importance. Nuclear radiation becomes an important factor in shelter design when it threatens personnel, equipment, and structures. It is not a governing factor in shelter design, but it requires design modifications to insure adequate radiation protection.

b. Neutrons and Gamma Rays. Initial nuclear radiation is emitted within 1 minute after the detonation. The *alpha* particles (helium nuclei) and *beta* particles (electrons) are of such short range that for initial nuclear radiation they can be ignored. The *gamma* rays and *neutrons* emitted can travel considerable distances through the air and produce harmful effects in living organisms. Therefore, the incident radiation dose at various distances must be known. The shielding needed to reduce the incident dose to an acceptable level will be discussed later (paras. 33–36).

31. The RAD

To express the absorbed dose from gamma radiation (of X-rays) at any particular point, the *rad* is used as the unit of measurement. It is the energy imparted to matter by ionizing particles. It is not used to measure alpha and beta particles and neutrons. Recall that the interaction of gamma radiation with matter may produce ion pairs (ionization). A rad is the absorbed dose of any nuclear radiation which is accompanied by the liberation of 100 ergs of energy per gram of absorbing material.

32. Gamma-Ray Dose-Distance Relationship

a. Gamma-Ray Exposure Dose. The gamma-ray exposure dose from a nuclear detonation received at a particular location is less the farther that location is from the point of burst. Two factors cause this. One is the general de-

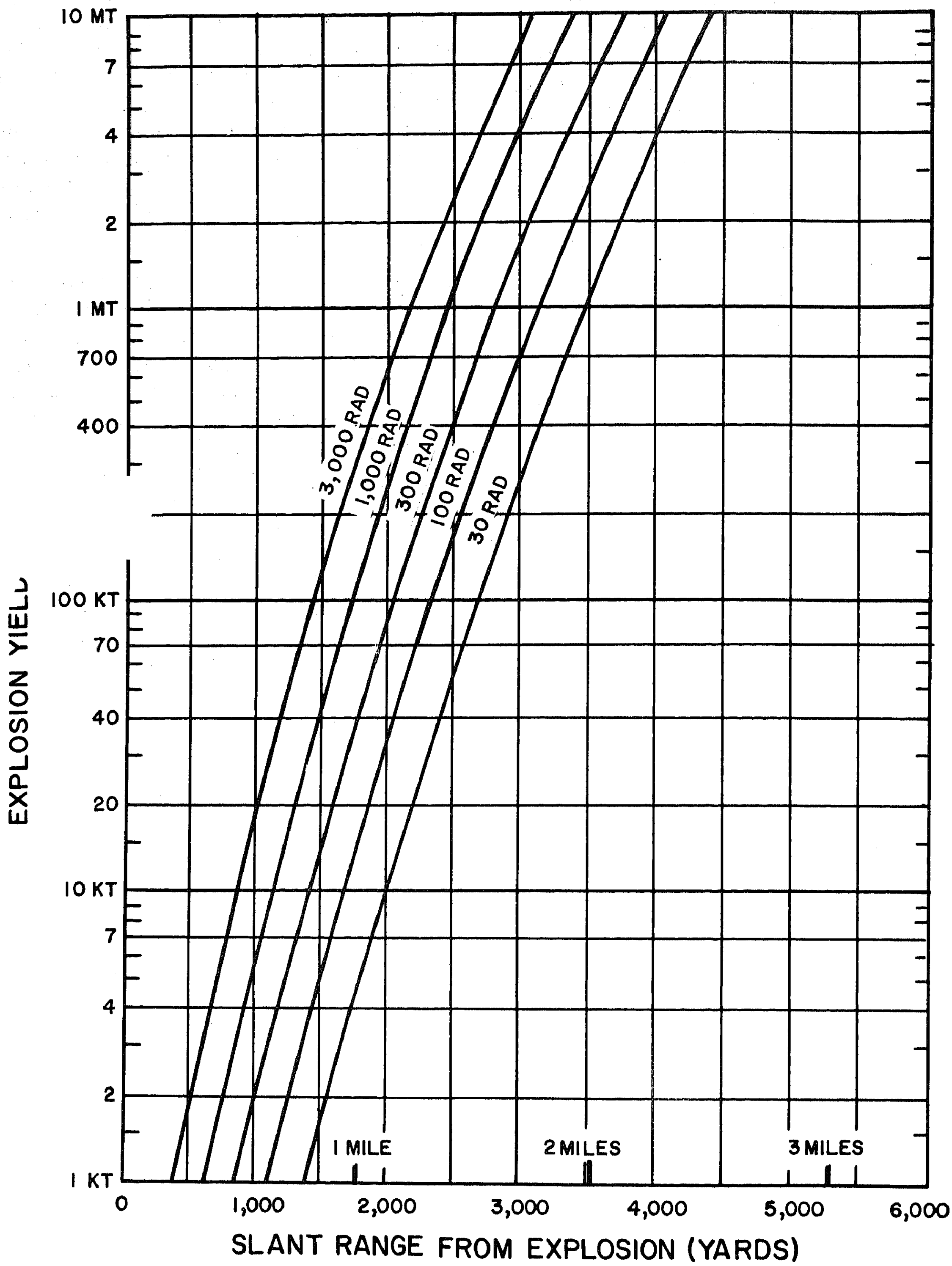


Figure 15. Slant ranges for specified initial gamma-ray doses as function of energy yield of the explosion.

crease because radiation spreads over a larger area as it travels away from GZ. It is inversely proportional to the square of the distance. The second factor is the attenuation resulting from the decrease in intensity due to the absorption and scattering of gamma rays by the intervening atmosphere. Gamma-radiation exposure doses at known distances from explosions of different energy yields have been measured. The results are summarized in figure 15.

b. Illustrative Example.

GIVEN: A 100–KT airburst.

FIND: The slant range of which 300 rad of initial gamma radiation would be received.

SOLUTION: From figure 15 the slant ranges from an explosion, at which certain specified doses of initial gamma radiation would be received, can be read off directly. In this case, the slant range may be interpolated to be 2,100 yards.

c. Applicability. The foregoing data are applicable only to airbursts. The dust and debris produced by a surface burst causes a reduction in the exposure does at any given slant range from GZ. Therefore, the dose-distance relationships vary with the height of burst, especially if the detonation occurs not too far above the earth's surface. Generally, the initial gamma-radiation dose from a surface burst may be taken as two-thirds that from an airburst at the same slant distance.

33. Shielding Against Gamma Rays

Gamma rays are attenuated (or absorbed) to some extent as they pass through any ma-

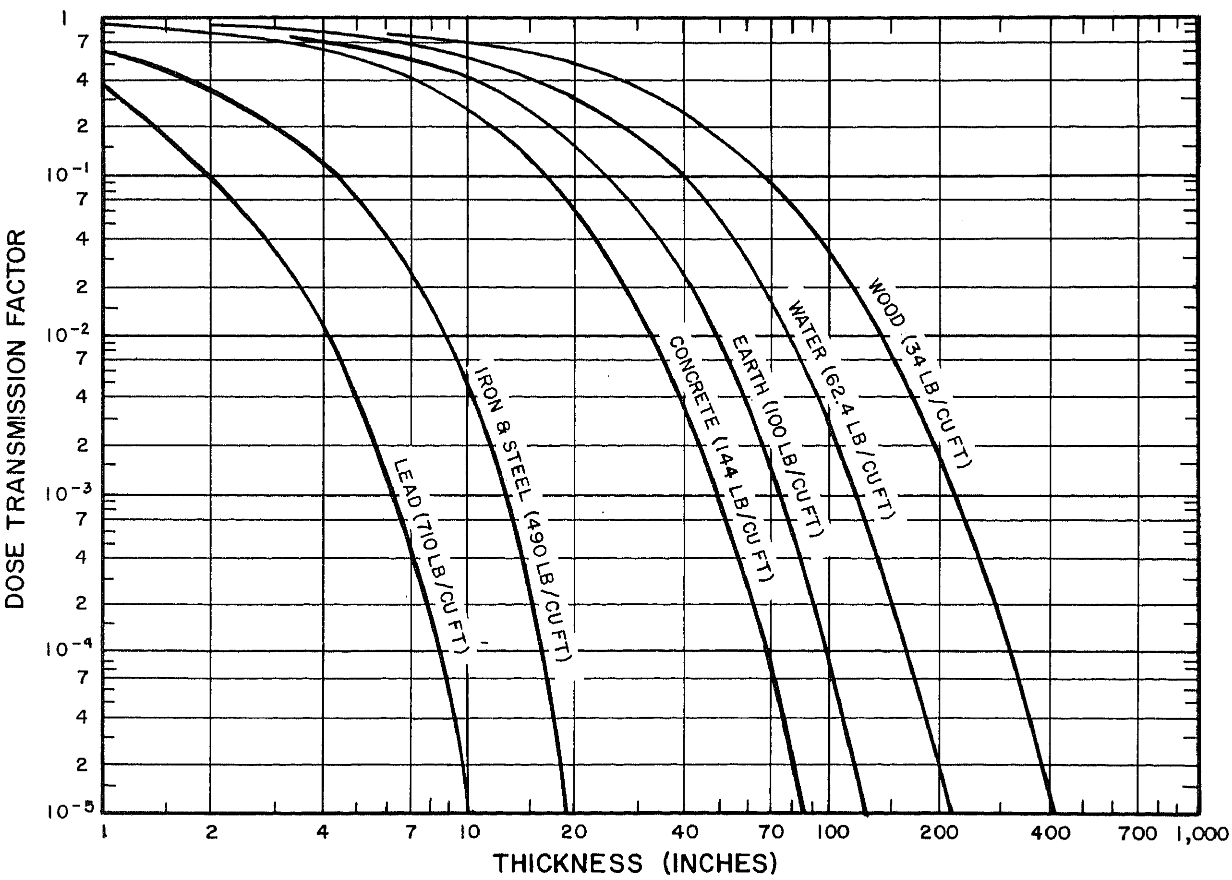


Figure 16. Attenuation of initial gamma neutrons by various materials.

terial. As a rough rule, the decrease in radiation intensity depends upon the mass of material that intervenes between the source of the rays and the point of observation. While it is not possible to absorb gamma rays completely, a sufficient thickness of material can reduce the exposure dose to negligible proportions. If there are no directives available which state otherwise, consider that enough radiation shielding should be provided to reduce the combined initial gamma and neutron dose to not over 20 rad.

34. Dose Transmission Factors

a. The dose transmission factor (or AF) is the fraction of the initial gamma radiation dose falling on the shield that actually reaches the target. Figure 16 shows the dose transmission factors of various materials.

b. As an illustrative example:

GIVEN: An initial gamma-ray exposure dose without shielding to be 500 rads.

FIND: The dose that would be received behind an earth shield 5 feet (or 60 inches) thick.

SOLUTION: Figure 16 shows the dose transmission factor for 60 inches of earth to be about 4.0×10^{-3}. The

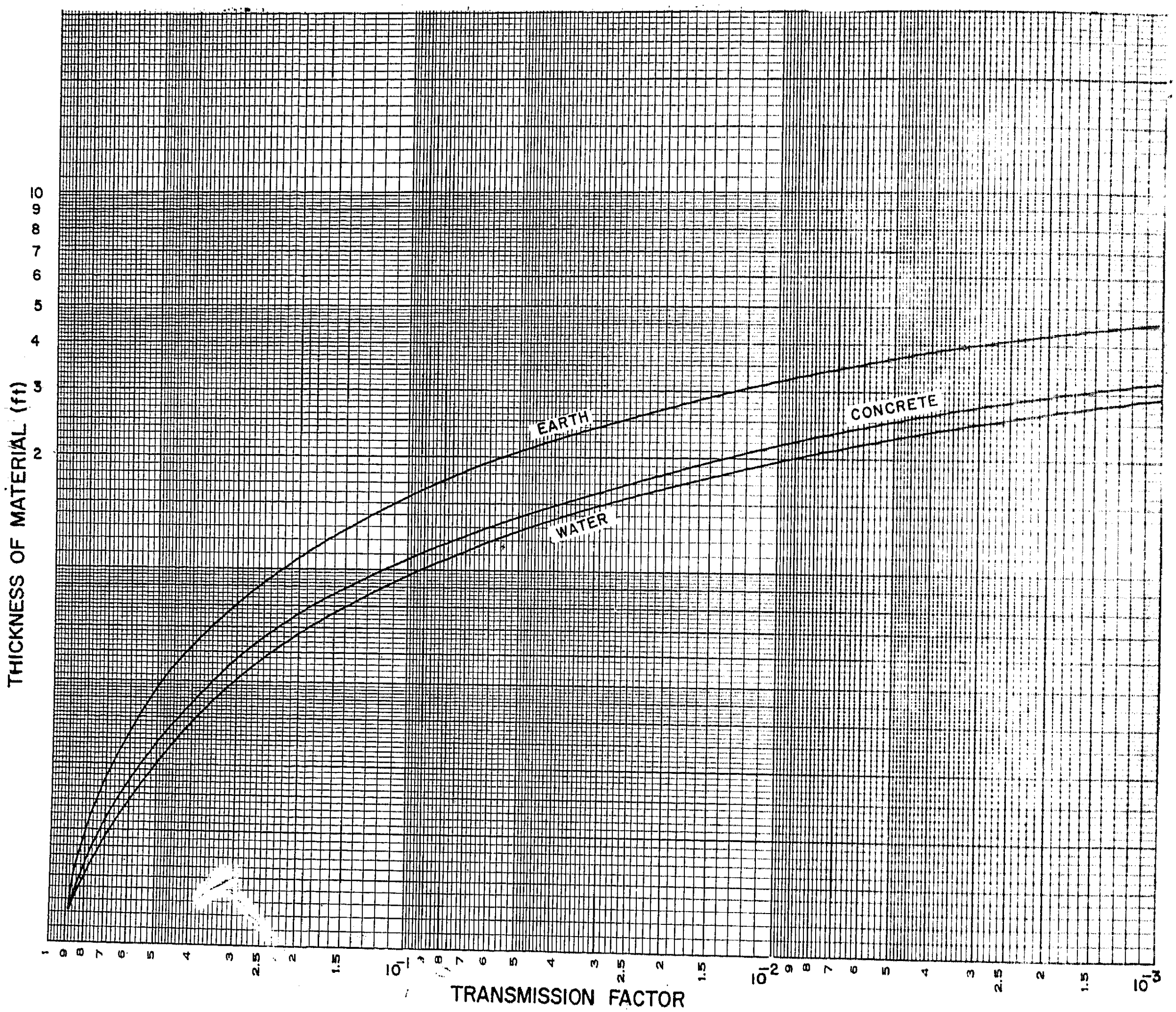


Figure 17. Attenuation of neutrons.

actual exposure dose received would be:

$500 \times 4.0 \times 10^{-3} = 2.0$ rad.

c. A second illustrative example:

GIVEN: An exposure dose of 500 rads.

FIND: The concrete thickness required to reduce this exposure dose to 1 rad.

SOLUTION: Transmission factor is 1/500, which is 2×10^{-3}. Figure 16 shows that on the curve for concrete this corresponds to a thickness of 45 inches, or 3 feet 9 inches.

d. Figure 17 may be used to solve similar problems in neutron attenuation.

e. In a vacuum, gamma rays travel in straight lines with the speed of light, but in the atmosphere gamma radiation is scattered, especially by nitrogen and oxygen. Gamma rays, therefore, reach the target from many directions, although most of the dose will come from the direction of the explosion. Gamma radiation reaching the target after scattering in the air is called *skyshine*. This poses a problem in shielding because a position behind a wall, embankment, or hill is a shield to some extent from direct gamma rays, but this position is exposed to skyshine. The broken lines in figure 18 show this. Adequate protection is shown in figure 19 where the shelter surrounds the individual so that he is shielded from all directions. The variation in the amounts of radiation received at a target from different directions is called *angular distribution*. Angular distribution of initial gamma radiation is relatively insensitive to type of weapon and the distance from GZ.

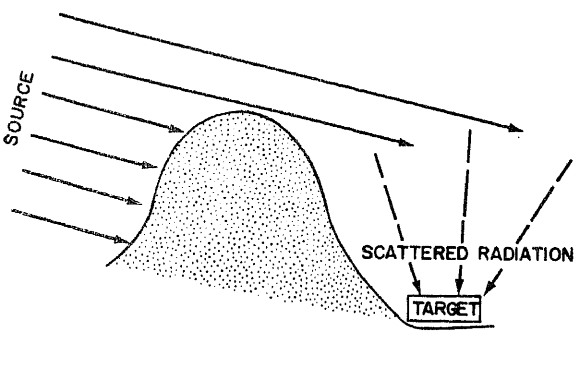


Figure 18. Target exposed to scattered gamma radiation.

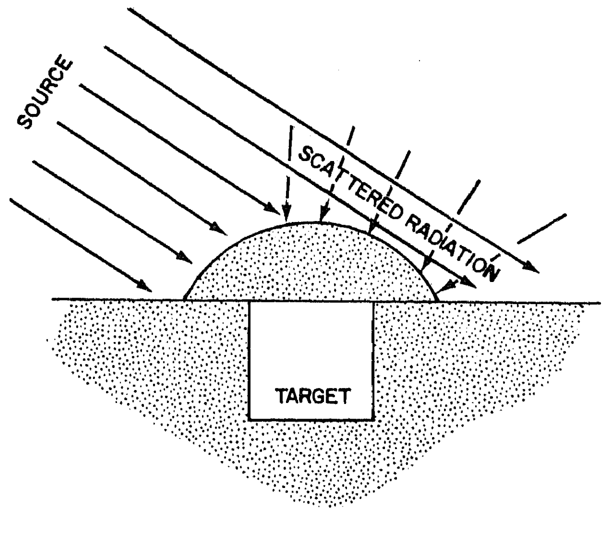


Figure 19. Target shielded from scattered gamma radiation.

35. Initial Gamma Radiation Shielding by Analysis

a. *Attenuation of Entranceway Gamma Radiation.* The initial gamma radiation reaching a shelter from the point of explosion will travel essentially along the line of sight. This radiation can enter a structure such as the one shown in figure 20 in two ways—through the entranceway and through the earth cover and corrugated steel plate section. To enter the shelter from the entranceway the radiation follows the path indicated on figure 20. First, the radiation must make essentially a right angle turn. This reduces the intensity of the radiation to about 0.07 of its line of sight value. (This value of 0.07 is based upon gamma radiation levels observed in foxholes, where the line of sight radiation also makes essentially a right angle turn.) To enter the horizontal portion of the entranceway, the radiation must make another right angle turn, which reduces the intensity by an additional factor of 0.07. The symbol AF_r will be used to indicate the attenuating effect caused by right angle turns in

radiation transmission. For two right angle turns, therefore, $AF_r = 0.07 \times 0.07 = 0.0049$.

b. Additional Effect. Radiation entering the horizontal portion of the entranceway is further attenuated because the cross-sectional area of the horizontal portion of the entranceway is greater than the cross-sectional area of the opening leading to it (fig. 20). This difference in cross-sectional area allows the radiation to spread out over a larger area and thus reduces its intensity. This attenuation effect is known as the *area effect* and will be designated by the symbol AF_a. The value AF_a is determined from the ratio of the two areas concerned. In this case

$$AF_a = \frac{\text{area of opening into horizontal entranceway}}{\text{cross-sectional area of horizontal entranceway}}$$

The area effect also attenuates the radiation when it passes from the horizontal entranceway into the shelter proper (fig. 20). In this case

$$AF_a = \frac{\text{cross-sectional area of horizontal entranceway}}{\text{cross-sectional area of shelter}}$$

c Attenuation Effect of Metal Entranceway. In addition, the gamma radiation is attenuated when it passes through the steel plate hatch and the steel plate entranceway door. The symbol AF_s will be used to represent these attenuation effects. Figure 16 gives the initial gamma radiation transmission factors for various types of materials (fig. 17 gives similar data for neutrons). The total transmission factor for the radiation which enters the shelter through the entranceway will be represented by the symbol AF_t. AF_t may be determined from the following formula:

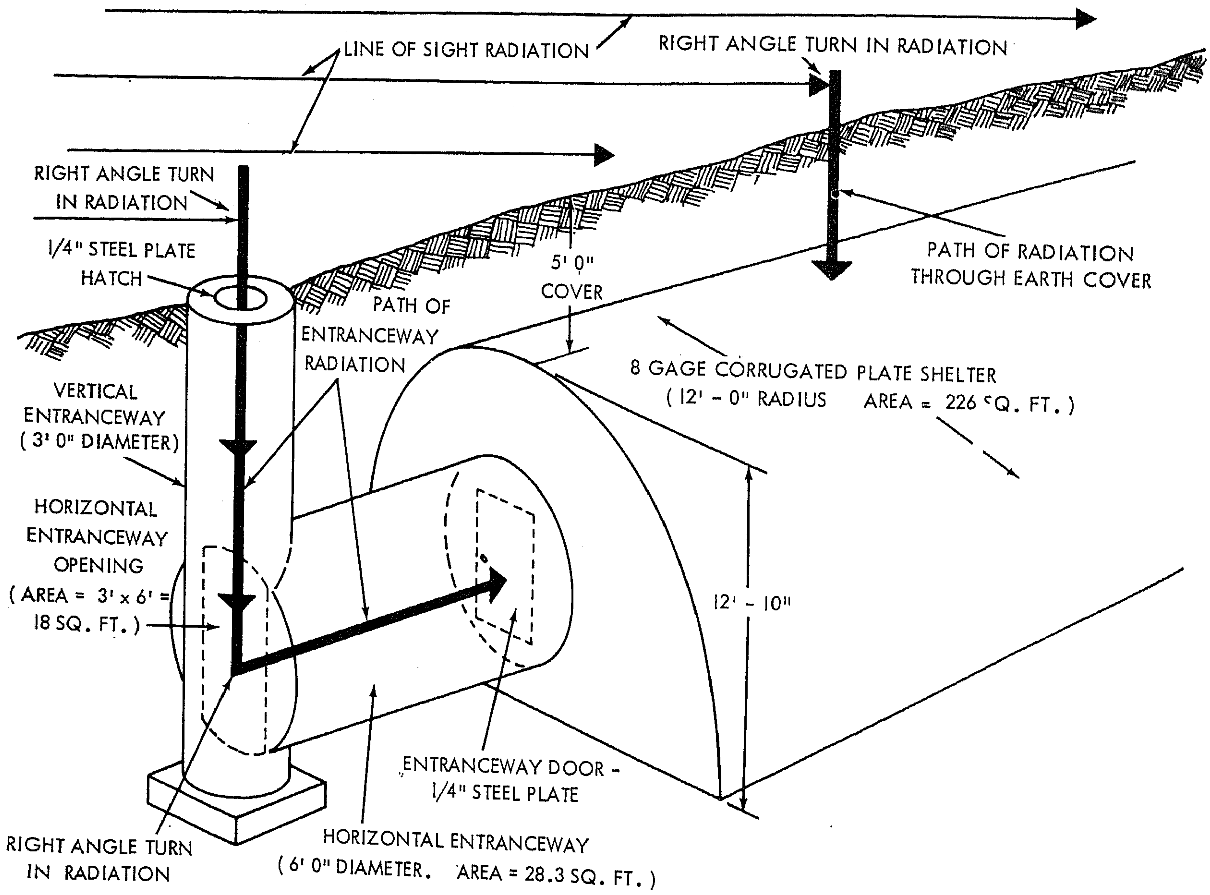


Figure 20. Typical personnel shelter (initial gamma shielding).

$AF_t = AF_r \times AF_s \times AF_a$

Where AF_r = transmission factor for right angle turns

AF_a = transmission factor due to the differences in cross-sectional areas of the structure through which the radiation passes

AF_s = transmission factor for the steel plate hatch and the steel plate entranceway door

d. Attenuation of Gamma Radiation Passing Through Earth Cover. The path followed by the gamma radiation passing through the earth cover is shown in figure 20. It is evident that this radiation must turn through essentially a 90° angle to pass through the earth in a perpendicular direction (figs. 16 and 17 are based on the assumption that the radiation is perpendicular to the slab of shielding material). As discussed previously this reduces the radiation by a factor of 0.07. The radiation must then pass through the thickness of earth cover (5 feet in this case) and the thickness of 8-gage corrugated metal plate (0.16 inch). The total transmission factor is represented by the formula:

$Af_t = AF_r \times AF_e \times AF_s$

Where AF_r = transmission factor for one 90° turn

AF_e = transmission factor for earth cover

AF_s = transmission factor for 0.16 inch of corrugated steel plate

36. Sources of Neutrons

While gamma rays are electromagnetic waves, neutrons are nuclear particles of appreciable mass whose harmful effects on the body are similar to those of gamma rays. Like gamma rays, only large doses of neutrons may be detected by human senses. Neutrons can penetrate a considerable distance through air. Their hazard is greater than might be expected from the small fraction of the explosion energy they carry (about 0.025 to 1.0 percent). Essentially all neutrons from a nuclear explosion are released either in the fission or fusion process. All neutrons from fusion and over 99 percent of the fission neutrons are produced within less than one millionth of a second of the initiation of the explosion. Those are the *prompt* neutrons. Also, less than 1 percent of fission neutrons (*delayed* neutrons) are emitted later, but within 1 minute, so they are part of the initial nuclear radiation. Figure 21 gives the intensity of neutron radiation at any distance from GZ for surface bursts of fission weapons.

37. Shielding Against Neutrons

Neutron shielding is a difficult problem. Materials that make good gamma-ray shields are not satisfactory for neutron shielding. The attenuation of neutrons involves several different phenomena. First, the very fast neutrons must be slowed down to a moderately fast range. This requires an inelastic scattering material, such as one containing barium or iron. Next, the moderately fast neutrons must be slowed down by elastic scattering, using an element of low atomic weight. Water is satisfactory for this process because it has hydrogen and oxygen. Then the slow (thermal) neutrons must be absorbed. The hydrogen in the water can do this. A difficulty, however, is that most neutron capture reactions include the emission of gamma rays. Therefore, sufficient gamma-attenuating material must be included to minimize the escape of capture gamma rays from the shield.

38. Shielding Materials

a. Generally, concrete or damp earth would be a fair compromise for neutron, and for gamma-ray, shielding. They do not have elements of high atomic weight. They have a fair proportion of hydrogen to slow down and capture neutrons, as well as calcium, silicon, and oxygen to absorb gamma radiations. Ten inches of concrete, for example, will decrease the integrated neutron flux by a factor of about 10; 20 inches by a factor of about 100. Initial gamma radiation would be decreased to a lesser extent, but concrete, in sufficient thickness, could provide shielding against neutrons and gamma rays. Damp earth could also meet the requirements but in 50 percent greater thickness.

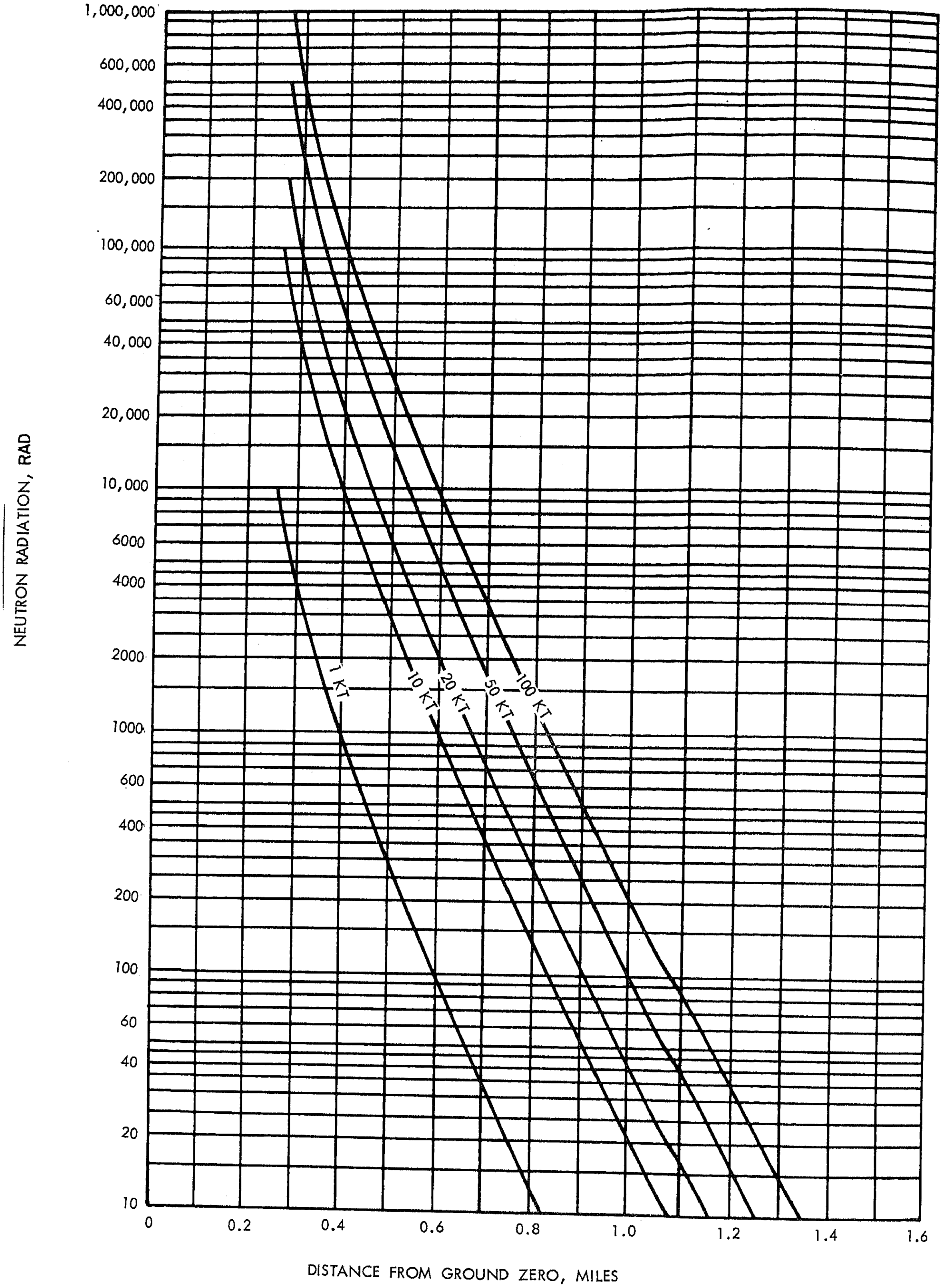


Figure 21. Neutron radiation, surface burst, fission weapon.

b. Absorption of nuclear radiations is increased by modified (heavy) concrete, made by adding a considerable proportion of an iron (oxide) ore (limonite, *for example*) to the mix and adding small pieces of iron or mineral barytes. A heavy element improves both neutron and gamma-ray shielding. To attenuate the integrated neutron flux by a factor of 10, about 7 inches of heavy concrete should be used.

c. Colemanite (a crystalline admixture of hydrous calcium borate) can be used in concrete to improve its ability to absorb neutrons.

39. Test Structures

a. Test Structure. Because of the lack of reliable theoretical data concerning neutron shielding, the information included in this section will be based upon empirical results. Twelve large-diameter buried conduit sections of various shapes were tested in the 56- to 153-psi (4 kg to 10.7 kg/sq cm) overpressure region on Shot Priscilla, Operation PLUMBBOB, Nevada Test Site, 1957. Shot Priscilla was detonated at a height of 700 feet (213.36m) and yielded 39.0 KT. The PLUMBBOB structure of particular interest for purposes of this discussion is the cattle-pass conduit personnel shelter shown in figure 22. This structure was located at a radial distance of 1040 feet (317 m) from ground zero. The measured free field neutron dose at this distance was 4×10^5 rad. The neutron dose measured inside the structure was 25 rad. The neutron transmission factor for this structure is about 6×10^{-5}; that is,

$$\left(\frac{25}{4 \times 10^{-5}}\right)$$

b. Other Structures. Radiation test results of other types of corrugated metal structures with 5 feet of earth cover have produced neutron transmission factors in close agreement with the value indicated above for the cattle-pass structure. It is recommended, therefore, that a neutron transmission factor of 1×10^{-4} be used to evaluate the neutron-shielding capacity of corrugated metal personnel structures with 5 feet of earth cover such as the one shown in figure 20. Data from Operation TEAPOT, Nevada Test Site, showed that below-grade shelters with 4 feet of vertical cover gave a neutron transmission factor of 1.5×10^{-6} for the high-energy neutron flux which would be detected by sulfur threshold detectors. It is felt, therefore, that the AF value of 1×10^{-4} is sufficiently conservative for shielding design purposes.

c. Recommended Neutron Transmission Factor. It is emphasized that the recommended neutron transmission factor value of 1×10^{-4} for below-ground shelters with 5 feet of earth cover applies to the shelter proper and not to the entranceway. All radiation measurements observed to date indicate that the neutron dose level in entranceways is considerably higher

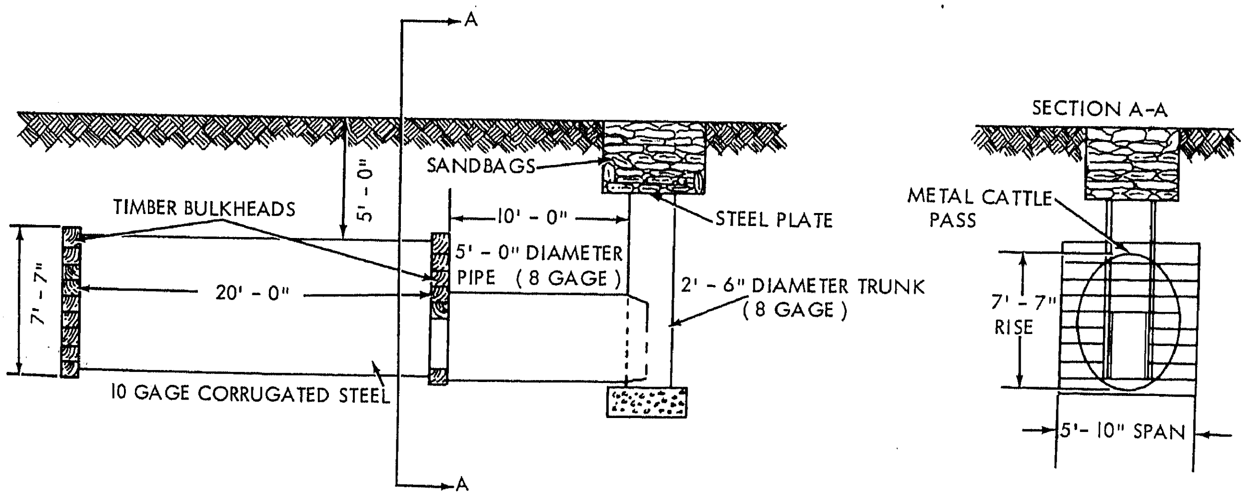


Figure 22. Cattle-pass conduit test structure (Operation PLUMBBOB).

than in the shelter proper. It is for this reason that an entranceway configuration similar to the one shown in figures 20 and 22 should be used. The horizontal portion of the entranceway has a significant attenuation effect on the neutron radiation entering through the entrance hatch. A neutron attenuation factor of 1×10^{-4} may be used for below ground reinforced-concrete shelters with 4 feet of earth cover if an entranceway configuration similar to the one shown in figure 20 is provided for the shelter.

d. Illustrative Example.

GIVEN: *Assume* that the personnel structure shown in figure 20 has been designed so that it will resist a 50-psi (3.5 kg/sq cm) incident overpressure (complete *structural* detail for this overpressure level is *not* shown on the figure). Consider a 100 KT surface burst at a distance that would produce the design overpressure. Gamma radiation is 60,000 rad.

FIND:

(1) The predicted level of initial gamma radiation inside the shelter if the shelter is placed at a distance where it is subjected to 50-psi (3.5 kg/sq cm) overpressure from a 100 KT weapon.

(2) The approximate level of neutron radiation inside the shelter.

(3) An estimate of the total initial nuclear radiation that will exist inside the shelter.

e. SOLUTION:

(1) *Initial gamma radiation attenuation.* 50-psi (3.5 kg/sq cm) overpressure occurs at a distance of 0.4 mile (0.64 km) for 100 KT (fig. 10).

Attenuation of entranceway radiation:

$AF_t = AF_r \times AF_a \times AF_s$

AF_r = transmission factor for 2 right angle turns

$= 0.07 \times 0.07 = 0.0049$

AF_a = transmission factor determined by two ratios:

(*a*) Ratio of area of horizontal entranceway opening to cross-sectional area of horizontal entranceway.

(*b*) Ratio of cross-sectional area of horizontal entranceway to cross-sectional area of shelter (fig. 20).

$$AF_a = \frac{18 \text{ sq ft}}{28.3 \text{ sq ft}} \times \frac{28.3 \text{ sq ft}}{226 \text{ sq ft}}$$

$$= \left(\frac{16{,}722 \text{ sq cm}}{26{,}300 \text{ sq cm}} \times \frac{26{,}300 \text{ sq cm}}{209{,}960 \text{ sq cm}}\right)$$

$= 0.0796$

AF_s = transmission factor for 1/4" (6.35 mm) steel entrance hatch and 1/4" steel entranceway door (0.9 each)

$AF_s = 0.9 \times 0.9 = 0.81$

$AF_t = AF_r \times AF_a \times AF_s = 0.0049 \times 0.0796 \times 0.81$

$= 3.16 \times 10^{-4}$

Intensity of radiation transmitted through entranceway:

$AF_t = 3.16 \times 10^{-4} \times 60{,}000$ rad = 19 rad

Attenuation of gamma radiation through soil and corrugated steel plate section:

$AF_t = AF_r \times AF_e \times AF_s$

AF_r = transmission factor for one right angle turn = 0.07

AF_e = transmission factor for 5 feet of earth = 0.003 (fig. 16)

AF_s = transmission factor for 8-gage corrugated steel plate

= 0.92

$AF_t = 0.07 \times 0.003 \times 0.92 = 1.93 \times 10^{-4}$

Intensity of radiation transmitted through soil and corrugated steel plate section:

$AF_t = 1.93 \times 10^{-4} \times 60{,}000$ rad = 12 rad

Total transmitted gamma dose = 19 rad + 12 rad = 31 rad

(2) *Neutron attenuation.*

At a distance of 0.4 mile (0.64 km) from a 100 KT detonation the neutron radiation level = 100,000 rad

(fig. 21). Use neutron transmission factor of 1×10^{-4} (para 39*b* above). Total transmitted neutron dose = $100{,}000 \times 10^{-4} = 10$ rad

Total nuclear radiation level inside shelter:

Total transmitted initial gamma dose = 31 rad

Total transmitted neutron dose = 10 rad

Total initial nuclear radiation level inside shelter = 31 rad + 10 rad = 41 rad

Note. This exceeds the recommended moderate risk initial dose of 20 rad

Section IV. THERMAL RADIATION

40. Radiation from the Fireball

a. General Characteristics of Thermal Radiation.

(1) An important difference between nuclear and conventional high-explosive weapons is the large proportion of energy of the nuclear weapon that is released as thermal (or heat) radiation. The temperature at the surface of the fireball is estimated to be several tens of millions of degrees. This heat is radiated (ultraviolet, visible, and infrared) from the fireball, traveling at the speed of light. At lesser intensities this heat is received at varying distances from the fireball. The term *thermal radiation* as used here means the part emitted within the first minute following the explosion.

(2) Although blast causes most of the destruction caused by nuclear weapons, thermal radiation contributes to the overall damage by igniting combustible materials, thereby starting fires in buildings or forests. Such fires can spread rapidly in the debris left by the blast. Thermal radiation can also cause skin burns and eye injuries to exposed individuals at a considerable distance from an explosion. The injuries from thermal radiation become more marked with increasing yield of an explosion.

b. Attenuation of Thermal Radiation. Thermal energy falling upon an area is less when farther away from an explosion because the radiation spreads over an increasing area as it moves away from GZ, and because it attenuates as it moves through the air. The quantity of radiation varies inversely with the square of the distance from the explosion. Attenuation in the atmosphere results from absorption and scattering. Absorption causes thermal radiation to decrease markedly with the distance from GZ. Scattering leads to a somewhat diffuse, rather than direct, transmission of thermal radiation. The curve in figure 23 shows the relationship between thermal energy and distance.

c. Effect of Atmospheric Conditions. The above-mentioned decrease in energy also depends upon atmospheric conditions, the concentration and size of particles, and the wave length of the radiation. Although wave lengths vary, a mean attenuation (averaged over all wave lengths) will be used in this manual. To determine scattering, the atmosphere is represented by daylight "visibility range." Table VI gives the international code to correlate visibility with atmospheric conditions. Because attenuation increases with the distance from an explosion, at distances less than one-half the visibility range attenuation varies no more than about 35 percent for conditions between light haze and very clear (10 to 50 kilometers, or 6 to 31 miles). This is less than would be expected; the reason is that thermal radiation at a given distance from GZ includes both directly transmitted and scattered radiations. Clear air with few particles causes little scattering. Radiation is then transmitted directly. With a moderately large number of particles in the air there is less direct radiation but an increase in scattered radiation. If rain, fog, or a dense industrial haze exist, absorption must be considered.

Table VI. Visibility and Conditions of the Atmosphere

Atmospheric condition	Visibility	
	Kilometers	Miles
Exceptionally clear	280	174
Very clear	50	31
Clear	20	12
Light haze	10	6
Haze	4	2.5
Thin fog	2	1.2
Light to thick fog	1 or less	0.6 or less

d. Effect of Smoke and Fog. From an airburst above a layer of dense cloud, smoke, or fog, much of the thermal radiation is scattered upward. It may then be considered lost to any particular point on the ground. Also, radiation that penetrates the cloud or fog is scattered. These effects substantially decrease the thermal energy reaching a ground target covered by smoke or fog.

e. Effect of Shielding.

(1) Unless scattered, thermal radiation travels in straight lines from the fireball. Solid, opaque material (wall, hill, tree, or similar object) acts as a shield from thermal radiation. Thermal radiation is only slightly attenuated by transparent materials.

(2) To be effective, a shield must surround the target under hazy atmospheric conditions. Much of the radiation received, particularly at considerable distances from GZ, is scattered. It then arrives from all directions.

f. Type of Burst.

(1) In *a* through *e* above, the information dealt with thermal radiation from an airburst. From other types of bursts the general effects are the same, although they differ in degree. With a surface burst the amount of energy appearing at a distance is less than for an airburst, first, because some shielding comes from terrain irregularities, and secondly, the low layer of dust or water vapor near the burst point absorbs some radiation. Also, most of the thermal radiation reaching a certain area on the ground has traveled through the air near the earth's surface. More absorption and scattering takes place there. As a result, the amount of thermal energy from a surface burst may be from three-fourths to one-half that from an airburst of the same yield and distance.

(2) In subsurface bursts nearly all thermal radiation is absorbed, providing there is no appreciable penetration of the surface by the fireball. With penetration, thermal energy is used up in heating and melting the soil or vaporizing the water. Normal thermal radiation effects do not exist.

(3) For nuclear explosions at high altitudes, the thermal X-rays from hot weapon residues are absorbed in a large volume of air because of the low density of the atmosphere. Fireball temperatures are lower than for airbursts, and thermal radiation is emitted more slowly. The air may absorb 50 to 70 percent of the explosion energy. Only about one-half of the energy is emitted rapidly enough to realize effective thermal radiation as discussed in *a* above. For bursts between 100,000 and 350,000 feet (30.5 and 107 kilometers), thermal radiation has only about 25 to 35 percent of total energy yield of the weapon.

41. Thermal Radiation Effects

a. Absorption of Thermal Radiation. Figure 23 shows the variation of thermal energy with distance and weapon yield for an airburst. Figure 24 is a plot of thermal radiation from a surface burst. As it leaves the fireball, thermal radiation covers a wide range of wave lengths (ultraviolet, visible, infrared). Much of the ultraviolet is absorbed or scattered in passing through the atmosphere, yet the ultraviolet rays can cause more biological damage than visible or infrared rays.

(1) When it falls upon any object, part of thermal radiation is reflected, part is absorbed, and what remains passes

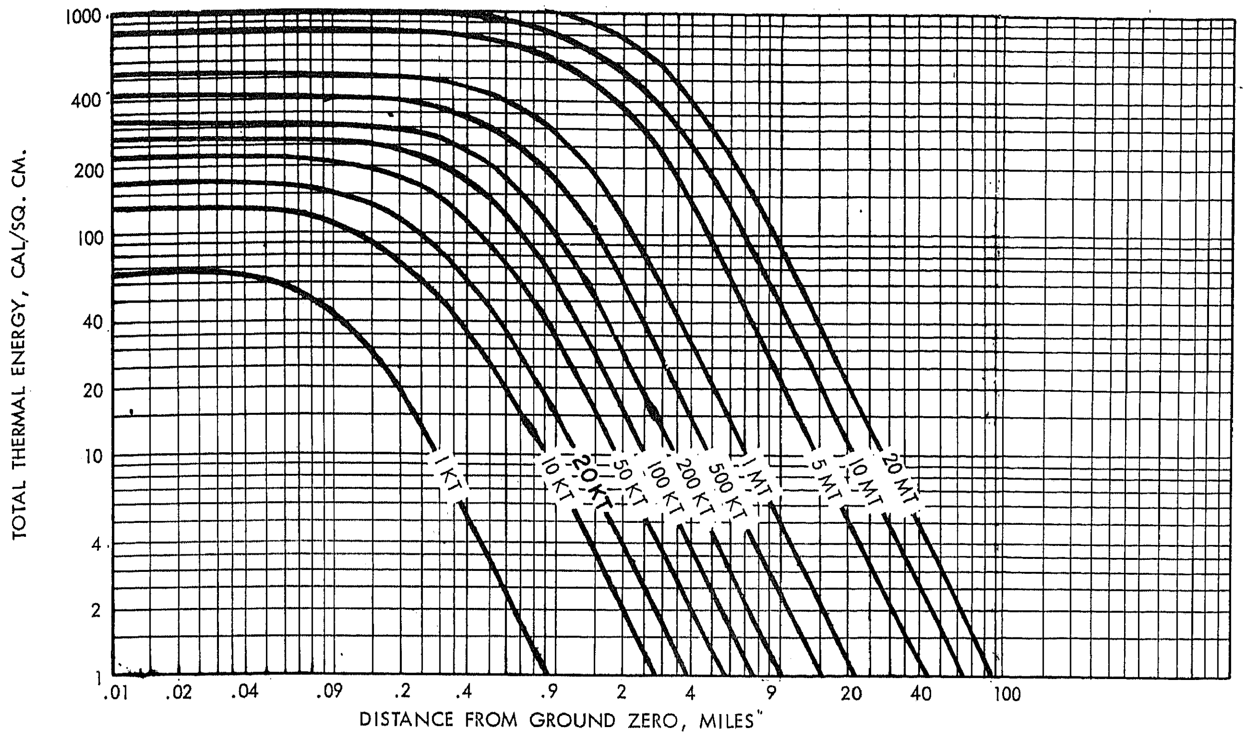


Figure 23. Total thermal energy, typical airburst, height in feet = 650 w ⅓ (w = weapon yield in KT).

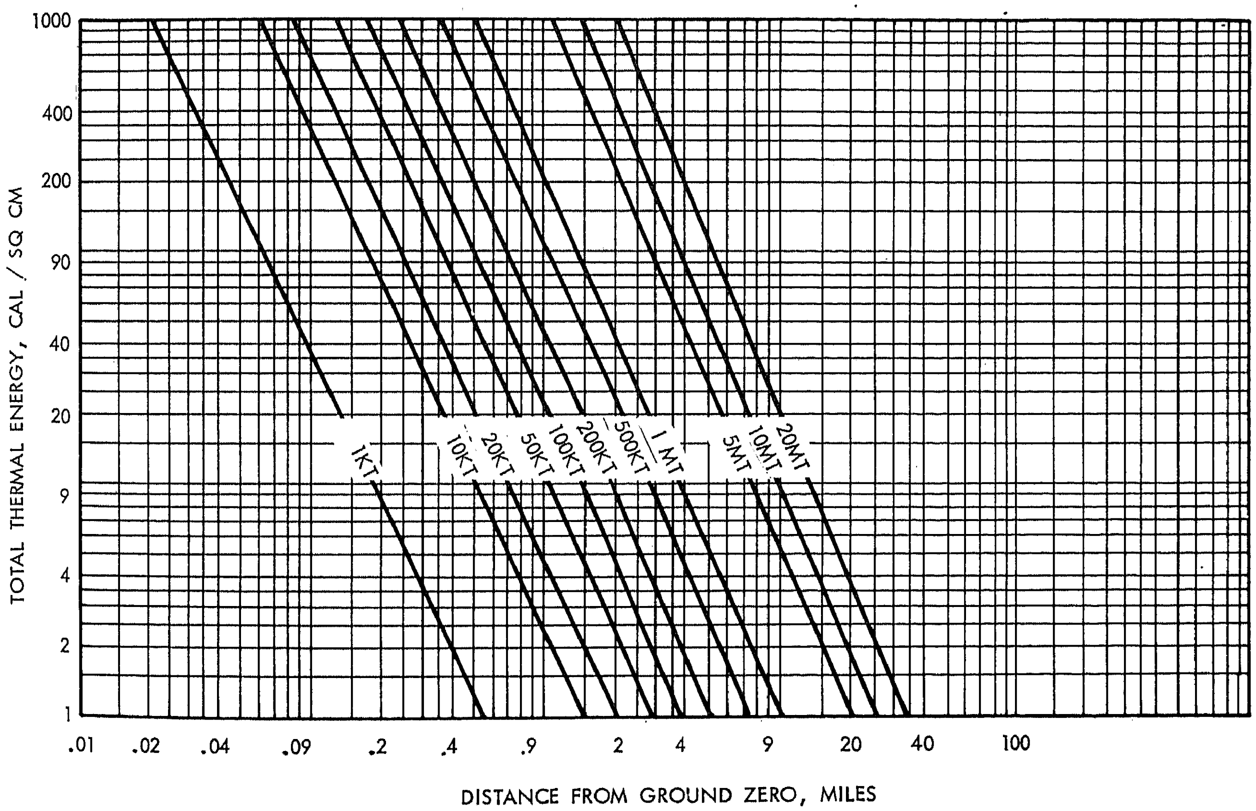


Figure 24. Total thermal energy, surface burst, visibility 10 miles.

through and falls upon other materials. The radiation absorbed produces heat and causes damage to the material. How much incident radiation is absorbed depends upon the nature and color of the material. Black fabric absorbs more incident radiation than white.

(2) The energy of thermal radiation is emitted in a very short time; its intensity is very high and heat is produced very rapidly. The absorbed energy is confined to shallow depth, with the result of very high temperature at the surface.

b. Effects.

(1) Physical results of the high temperatures are burning of skin, and scorching, charring, and possibly ignition of materials such as wood or paper. Whether a material is burned or charred depends upon thickness, moisture content, and temperature. Table VII indicates the exposure needed to ignite various fabrics by thermal radiation. The values given are in terms of gram-calories upon a 1-sq-cm (0.15-sq-in) area. This is generally referred to as *radiant exposure.* Values are higher in the megaton column because the rate at which thermal energy is delivered is an important factor in the charring and igniting of materials and causing skin burns. Rapid delivery causes more damage than slow delivery. Energy is produced more slowly in a high yield explosion. From thermal radiation pulses of short duration, energy may be less effective when delivered in a short pulse (fraction of a second) than one of moderate duration (1 or 2 seconds).

(2) Roughly speaking, about 10 or 15 calories per square centimeter of thermal energy are needed to produce visible charring of such woods as unpainted and unstained pine, douglas fir, redwood, or maple.

(3) Glass is highly resistant to heat, but the layers of plastic in shatterproof glass make the latter subject to decomposition by heat. However, some plastic materials (bakelite, cellulose acetate, lucite, or plexiglass) withstand thermal radiation; at least 60 to

Table VII. Approximate Radiant Exposures for Ignition of Fabrics.

Material	Weight		Ignition exposure* (cal/sq cm)		
	Oz/sq yd.	Gr/sq M.	40 KT	1 MT	10 MT
Rayon gabardine (black)	6	203.4	9	20	26
Rayon-acetate drapery (wine)	5	169.5	9	22	28
Rayon gabardine (gold)#	7	237.3	(**)	24	28
Rayon twill lining (black)	3	101.7	7	17	25
Rayon twill lining (beige)	3	101.7	13	20	28
Acetate-shantung (black)#	3	101.7	10	22	35
Cotton chenille bedspread (light blue)#	--	----	(**)	11	15
Cotton venetian blind tape, dirty (white)	--	----	10	18	22
Cotton muslin oiled window shade (green)	8	271.2	7	13	19
Cotton corduroy (brown)	8	271.2	11	16	22
Cotton canvas (O. D.)	12	406.8	12	18	28
Cotton denim, new (blue)	10	339.0	12	27	44
Cotton venetian blind strap (white)#	--		13	27	31
Cotton shirting (khaki)	3	101.7	14	21	28
Cotton heavy draperies (dark color)	13	440.7	15	18	34

* The values given are for near sea level detonations. Ignition levels (except where marked #) are estimated to be valid within ±25 percent under standard laboratory conditions. Under typical field conditions, the values listed are estimated to be valid within ±50 percent with a greater likelihood of higher rather than lower values. For materials marked #, ignition levels are estimated to be valid within ±50 percent under laboratory conditions and within ±100 percent under field conditions.

** Data not available, or appropriate scaling not known.

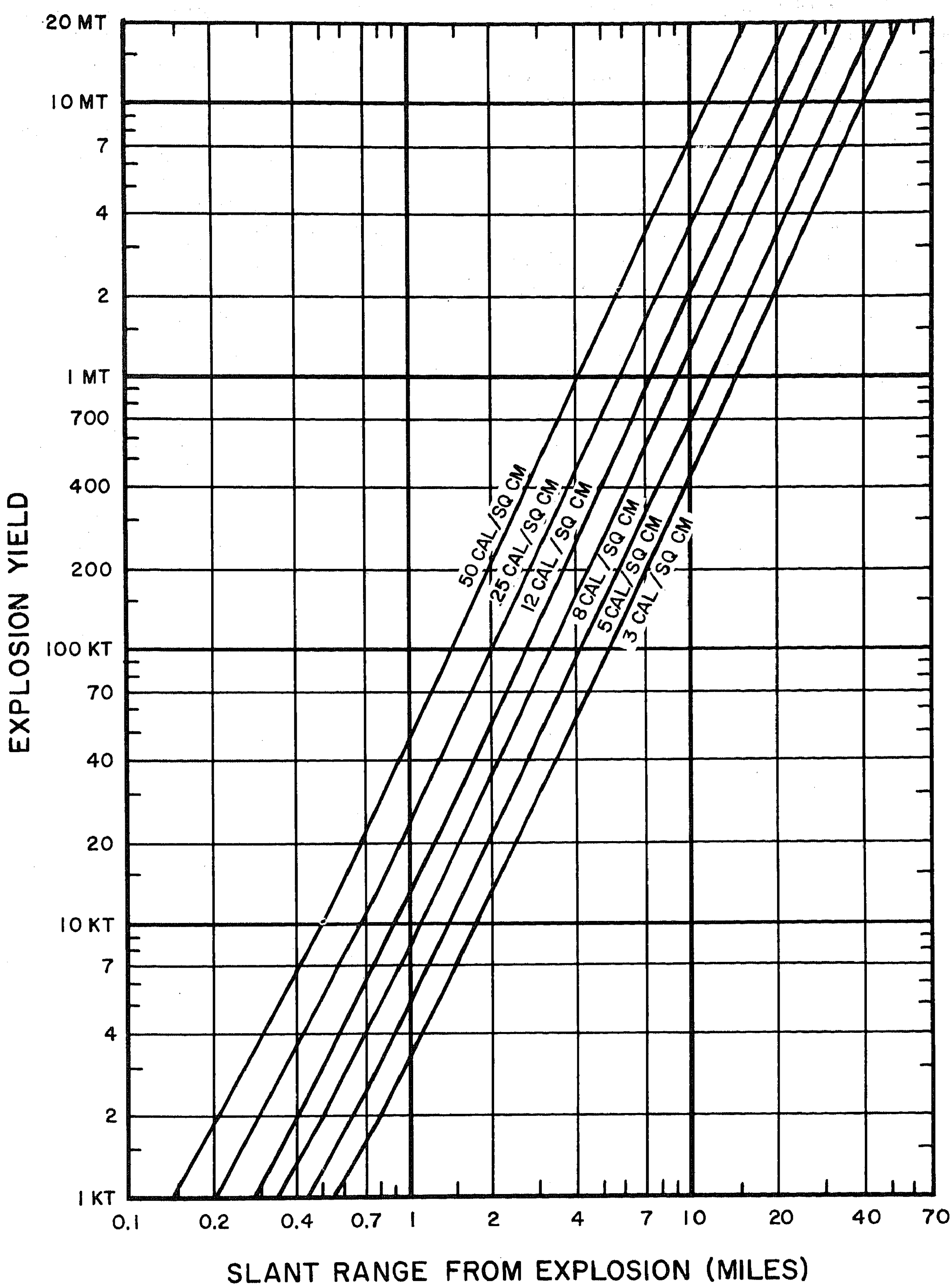


Figure 25. Slant ranges for specified radiant exposures as function of energy yield of the explosion.

70 cal/sq cm (387 to 452 cal/sq in) of thermal energy are needed to produce surface smelting or darkening.

c. Thermal Energy-Distance Relationships.

(1) Table VIII shows combustible materials which might start small fires. To use table VIII or IX to determine how far from GZ (for an explosion of a given energy yield) a particular material would ignite, it is necessary to know how the thermal energy varies with the distance for a particular yield. Figure 25 gives this information.

(2) Illustrative
GIVEN: 1-
FIND: R
w
1-

SOLUTION:
(*a*) Avera
ignite
terial
(table
(*b*) Enter
axis f
it int
cal/sq

Table VIII. Approximate Radiant Exposure for Ignition of Househol
Dry Forest Fuels

Materials	Weight	
	Oz/sq yd.	Gr/sq M.
Newspaper, printed text area	2	67.8
Paper, crepe (green)	1	33.9
Cotton string scrubbing mop, used (gray)#	--	----
Cotton string mop, weathered (cream)#	--	----
Matches, paper book, blue head exposed#	--	----
Deciduous leaves (beech)	--	----
Fine grass (cheat)	--	----
Coarse grass (sedge)	--	----
Pine needles, brown (ponderosa)	--	----

* The values given are for near sea level detonations. Ignition levels (except where marked #) a
percent under standard laboratory conditions. Under typical field conditions, the values listed are esti
cent, with a greater likelihood of higher rather than lower values. For materials marked #, ignition le
± 50 percent under laboratory conditions, and within ± 100 percent under field conditions.

(*c*) The above intersection point corresponds to about 8 miles (fig. 25), which is the range over which fires would be started from the thermal radiation.

42. Incendiary Effects

a. Origin of Fires.

(1) Incendiary damage has two causes—primary fires, which are ignited by the thermal radiation from the weapon itself, and secondary fires, which are ignited by the effects of the blast damage. No matter how the fire originates, its spread is determined by the amount and distribution of combustible materials in the vicinity. The problem of the development of fires after a nuclear explosion falls into two categories—the n
fires originat
the surround

(2) In analyzing
aspects of di
radiation are
tant appears
density of i
the number
area where
might be fou
the density o
est in wholes
residential ar
monest igniti
except in dow
awnings repr
of fire. The
enough to e

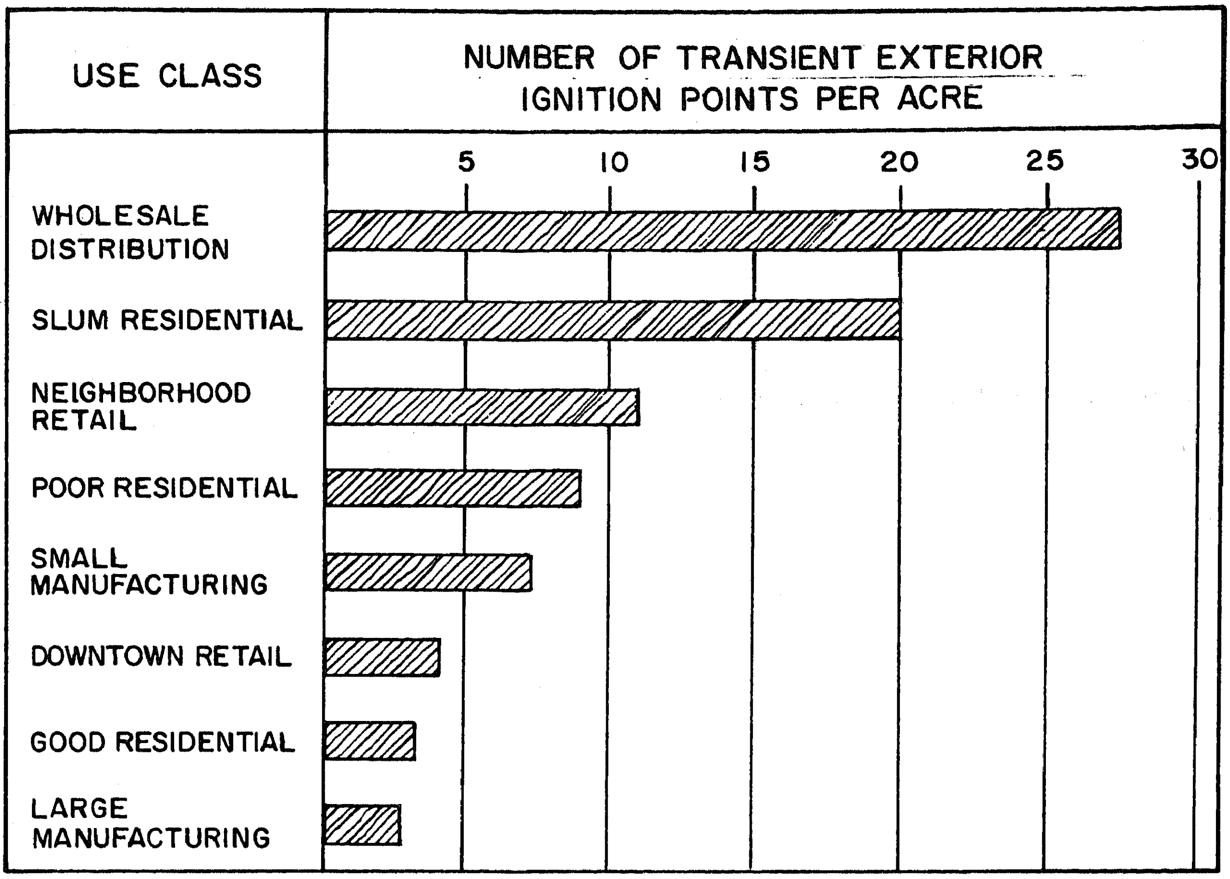


Figure 26. Frequency of exterior ignition points for various areas in a city.

fires that will actually occur. Too much depends on nearness to GZ, and on the amount of combustible materials close by.

(3) Because of the many uncertainties, interest should be directed more to the dangerous ranges for general classes of materials, rather than to specific values for specific materials. What constitutes significant damage to materials are those factors which are potential links in the development of mass fires or fire storms. The following circumstances are important:

(*a*) When flaming is produced which persists after the expiration of the thermal pulse.

(*b*) When there is a persistent afterglow or smoldering after the thermal pulse.

(*c*) In special cases, when a transient flame occurs on the surface during the thermal pulse that can ignite easily kindled adjacent material which is itself shielded from direct radiation.

b. Spread of Fires.

(1) The spread of fires in a city depends upon many conditions—weather, terrain, and closeness and combustibility of buildings, of which the last is most important. Figure 27 gives an idea of how the probability of fire spread depends upon the average distance between buildings in a city.

(2) Another aspect is the development of mass fires in a forest following primary ignition of dried leaves, grass, or wood by thermal radiation. Influencing factors are amount of moisture, topography, and weather conditions. Low humidity, strong winds, and steep terrain favor the spread of forest fires.

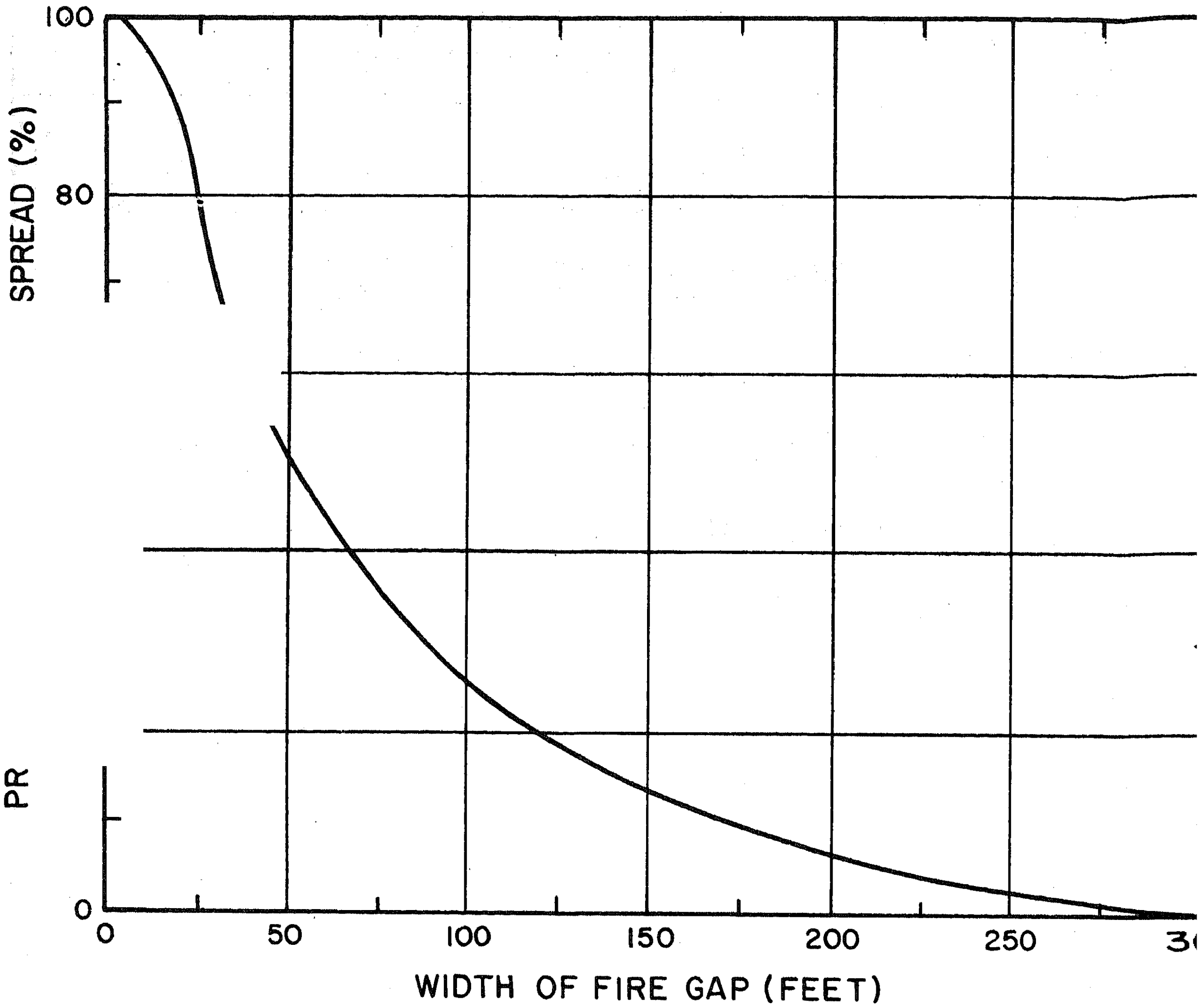


Figure 27. Width of gap and probability of fire spread.

Section V. RESIDUAL NUCLEAR RADIATION AND FALLOUT

43. Sources of Residual Radiation

a. Residual nuclear radiation is emitted later than 1 minute after the instant of explosion. Its characteristics vary relative to the fission and fusion contributions to the energy of the explosion. From a fission weapon, the radiation arises mainly from weapon residues (fission products) and, to a lesser extent, from uranium and plutonium which have escaped fission. The residues also contain some radioactive isotopes from the neutron reactions (other than fission) in the weapon materials. Residual radiation also comes from the interaction of neutrons with elements in the earth, the sea, the air other substances in the explosion environm Predominantly fusion weapons do not proc residues containing the same quantity of fis products that a fission weapon of the same y produces. A fusion weapon produces m high-energy neutrons, therefore residual ra tion in this weapon arises primarily from r tron reactions in the weapon and its surrou ings providing the fission yield is low.

b. Fallout is the primary hazard of resic radiation. Fallout particles incorporate radioactive weapon residues and induced ac

ity in the soil, water, and other materials in and around an explosion. Wind disperses these products over a wide area.

c. A secondary hazard of residual radiation may raise from neutron-induced activity on the earth's surface in the vicinity of the burstpoint.

44. Fallout

Fallout is in two parts—early and delayed. Early fallout reaches the ground during the first 24 hours after the detonation and produces enough contamination over large areas to be an immediate hazard. Delayed fallout arrives after the first 24 hours and consists of very fine, invisible particles settling in low concentrations over a large portion of the earth's surface. It threatens no immediate danger to health, but there may be a long-term hazard.

45. Fallout Prediction

A fallout prediction covers a general area outside of which a specific degree of hazard will probably not occur. The reliability of a fallout prediction depends on the reliability of the upper air wind data and the nuclear burst data upon which it is based. Secondarily, it depends on the prediction method used—the detailed or simplified. For detailed accounts of this subject, see TM 3–210 and FM 3–12.

a. Activity of Early Fallout.

(1) Fission products comprise a complex mixture of over 200 different forms (isotopes) of 36 elements. Most of these isotopes are radioactive. This radioactivity is initially very large, but it falls off rapidly because of radioactive decay.

(2) Uniform distribution of fission products after an explosion is improbable because a large proportion are deposited near GZ than at farther distances.

(3) Early fallout is mainly of fission products. The dose rate decreases with time. A rule-of-thumb would be that for every sevenfold increase in time after the explosion, the dose rate decreases by a factor of 10. This rule is accurate to within 25 percent up to to 2 weeks.

(4) An example of how to estimate the actual dose rate at any time after fallout is to use table IX. This table applies to *dose rates.* To determine the actual or total dose received, multiply the average dose rate by exposure time.

b. Infinity Dose. Table X shows the percentage of the *infinity (residual radiation) dose* that would be received from a given quantity of early fallout, computed from 1 minute to various times after an explosion. The infinity dose is essentially the dose that would be received by continued exposure to a certain quantity of early fallout for many years. The data in table X are useful to determine the proportion of the infinity dose received during any specified period following the complete deposition of the early fallout from a nuclear explosion. *For example,* an individual exposed to early fallout during the interval from 2 to 14 hours after an explosion may receive a percentage of the infinity dose obtained by subtracting the values in table X, that is, 76, for 14 hours, minus 62, for 2 hours, or 14 percent (0.14) of the infinity dose. By using tables IX and X many calculations concerning radiation dose rates and total doses received from early fallout can be made, if the quantity of fallout is not changed.

Table IX. Relative Theoretical Dose Rates From Early Fallout At Various Times After A Nuclear Explosion

Time (hours)	Relative dose rate (rad/hr)	Time (hours)	Relative dose rate (rad/hr)
1	1,000	36	15
1½	610	48	10
2	440	72	6.2
3	230	100	4.0
5	130	200	1.7
6	100	400	0.70
10	63	600	0.42
15	40	800	0.31
24	23	1,000	0.24

c. Contamination.

(1) The earth's surface can become contaminated with radioactive material from a nuclear explosion by induced activity and by fallout. Contamination and its distribution are dependent

principally upon energy yield, height of burst, nature of the surface, and meteorological conditions. An airburst carries up no significant quantities of surface material into the fireball. Radioactive residues of the weapon remain suspended in the atmosphere for a long time. There will probably be no early (or local) fallout, but there will be contamination in the vicinity of GZ because of neutron capture. It is possible that the area of GZ will be devastated by blast and fire.

Table X. Percentages Of Infinity Residual Radiation Dose Received From 1 Minute Up To Various Times After Explosion

Time (hours)	Percent of infinity dose	Time (hours)	Percent of infinity dose
1	55	72	86
2	62	100	88
4	68	200	90
6	71	500	93
12	75	1,000	95
24	80	2,000	97
48	83	10,000	99

(2) Lower height of burst carries debris from the earth up to the fireball. Fission and other radioactive products condense onto particles ranging in diameter from less than 1 micron (one millionth of a meter) to several millimeters. The total radioactivity in early fallout (early fallout fraction) varies from one explosion to another.

(3) Prediction of fallout pattern involves uncertainty because it depends upon the wind velocity, the size of the radioactive cloud, and the range of particles sizes. The area of peak concentration of radioactivity in a cloud seems to vary with different detonations.

(4) Fallout from a surface burst can produce serious contamination far beyond the ranges of other effects of a nuclear explosion. Contamination from fallout is one of the major effects of nuclear weapons. The wind pattern is a factor in determining the area covered as well as the distribution with that area.

Also, there are the effects irregularities in terrain.

d. Fallout Patterns. (For informa phase, see the prediction system e TM 3–210.)

e. Idealized Fallout Patterns.

(1) Idealized fallout patterns to represent the average 1 for a given yield and winc They are useful in planning in estimating the overall ef out.

(2) The basic fallout phenomer face burst in the KT-energ about the same as for h detonations. Table XI show rate contour dimensions fc surface burst with a 15-m

46. Attenuation of Residual Nucl Radiation

a. Alpha and Beta Particles.

(1) Because of their short ra particles from radioactive s not penetrate the skin. The alpha particles arising fro outside the body, attenua problem.

(2) Beta particles have a grea than alpha, but it is still ins People in a house would be from beta radiation from t Only beta radiation inges contact with the skin poses

b. Gamma Radiation.

(1) Residual gamma radiations dangerous. They can pene

Table XI. Downwind Extent Of Unit-Tim Dose-Rate Contours For 20-KT Surfac With 15-MPH Wind

Reference dose rate (rad/hr)	Downwind distance (miles)	Maxin (m
3,000	1	und
1,000	3	und
300	7	
100	14	
30	32	
10	60	
3	100	
1	150	

distances. Shielding is needed to reduce gamma radiations to an acceptable level.

(2) The absorption of residual gamma radiation from fission products and radioisotopes produced by neutron capture is based on the same principles as described in paragraphs 32 through 34 on initial gamma radiation. Residual gamma rays are easily attenuated. Calculation of this attenuation of gamma radiation from fallout is more complicated in some ways than that of initial radiations. The effctiveness of a given thickness of material is influenced by the fallout distribution. Esimates of attenuation in typical residential structures have been made. Brick veneer gives a better protection than a frame dwelling. Table XII gives the protection factors at various locations in typical residential structures.

Note. The protection factor is the ratio of the dose which would be received outdoors, without any protection, to that received at the indicated location in the structure.

Table XII. Protection Factors Of Various Locations In Typical Residential Structures

First floor area		Type of structure			
		One-story brick veneer		One-story frame	
		Location			
sq ft)	(sq m)	Center of ground floor	Center of basement	Center of ground floor	Center of basement
1,000	93.0	3.4	22	2.3	20
1,200	111.0	3.1	18	2.2	17
1,500	139.3	3.1	16	2.3	15
2,000	186.0	3.0	14	2.2	13

First floor area		Two-story brick veneer		Two-story frame	
		Location			
sq ft)	(sq m)	Center of ground floor	Center of basement	Center of ground floor	Center of basement
1,000	93.0	4.4	54	2.3	44
1,200	111.5	4.4	41	2.4	37
1,500	139.3	4.4	37	2.4	34
2,000	186.0	4.1	34	2.4	29

47. Delayed Fallout

a. Introduction. Both early and delayed fallout are briefly discussed in paragraphs 43 through 45*b*. Delayed fallout is specially important in two respects—many contaminated particles remain aloft for a long time so delayed fallout spreads over large areas, and among the radioisotopes remaining aloft are strontium-90 and cesium-137, both of which have biological significance because they can get into food.

b. Influence of the Atmosphere. Temperature varies in the atmosphere, depending on altitude, latitude, and time. There are several levels in the atmosphere, from the troposphere (25,000 to 45,000 feet or 7.6 to 13.7 km altitude; in tropics, 55,000 feet or 16.7 km altitude), through the stratosphere (45,000 to 90,000 feet or 13.7 to 28.9 km), and mesosphere (125,000 to 250,000 feet or 38.1 to 76.2 km), on to the ionosphere and thermosphere (over 250,000 feet or 76.2 km). Most visible weather phenomena occur in the troposphere. Clouds are formed there, causing rainfall. A jet stream is located at the tropical edge of the polar troposphere in each hemisphere.

48. Residual Nuclear Radiation Shielding

Since the induced radiation from surface and subsurface bursts is relatively insignificant when compared to the extensive contamination caused by fallout radiation, this section will cover only fallout radiation shielding. The problem of shielding from fallout radiation is different from that of initial nuclear radiation shielding. The major differences are—fallout radiation contains no neutrons; radiation from fallout particles persists for a long time; the radioactive particles are spread over large areas; the energy of the radiation from fallout is lower than the initial gamma radiation, and hence a given thickness of material will have a greater attenuating effect on fallout gamma radiation than on initial gamma radiation. Although the fission products which produce the radioactive fallout radiation emit beta and alpha particles as well as gamma rays, only the gamma radiation has significant penetrating power. Only the gamma radiation, therefore, need be considered in fallout radiation shielding.

49. Terminology and Technology

a. Symbols.

A_L	Loaded area
A_c	Core area
A_p	Apertures fraction $\left(\frac{\text{aperture area}}{\text{total wall area}}\right)$
A_r	Area of roof cover detector
C_c	Central roof area contribution
C_g	Ground contribution
C_g	Aboveground contribution
C_o	Overhead contribution
C_p	Peripheral contribution
d	Distance of detector from opening
H	Detector height above contaminable ground
H_c	Height correction factor
K_b	Correction factor for basement exposure
MS	Mutual shielding correction factor
P_f	Protection factor (residual number)
R_f	Total reduction factor
W	Width of opening
W_c	Width of rectangular strip of contamination
X	Mass thickness (in psf)
X_b	Basement wall mass thickness
X_c	Corridor wall mass thickness
X_d	Divider partition mass thickness
X_e	Exterior wall mass thickness
X_f	Single floor mass thickness
X_i	Interior wall mass thickness
X_o	Total overhead mass thickness
X_o	Ground floor mass thickness Floor immediately over basement mass thickness
X_p	Roof area mass thickness
X_r	Roof mass thickness
X_w	Wall mass thickness
Z	Distance from detector to roof

b. Detector's Position. This is any fictitious position that might be occupied by an individual within a structure to find the relative reduction of radiation that the structure provides.

c. Source of Radiation. Primary sources are those locations where fallout particles have come to rest. Only two locations are considered here—on the *roof* of the structure, and on the *ground* surrounding the structure. Secondary sources are shields that become a new source because the radiation coming through is partially modified. An example would be an exterior wall or roof.

d. Shielding Effects. Shielding effects are attenuations of the gamma radiations obtained either by interposing a barrier between the source and the detector, or by moving the detector away from the source. The first method is known as "barrier shielding" and the second as "geometry shielding."

e. Barrier Shielding. Barrier shielding is the attenuation caused by wall, roofs, and floors. This shielding effect depends on three things—the *mass* of the barrier, the *type* of source, and the *position* of the barrier with respect to the source.

(1) An exterior wall (X_e) and a floor over a basement area (X_o) of the same thickness* ($X_e = X_o$) will have different shielding effects because they are "concealing" different types of sources. The wall is "concealing" a primary source (the contaminated ground) and the floor above the detector is "concealing" radiation from a secondary source (the exterior wall).

(2) A roof (X_o) and an exterior wall of the same mass thickness are concealing the same type of source, that is, a primary source, but they have different shielding effects because of the position of the barrier with respect to the source. In the case of the wall, the source is considered to be located on a contaminated plane of infinite extent. In the case of the roof, the source is lying right on top of the overhead barrier.

(3) It is apparent that each different barrier will have a shielding factor of its own before its mass thickness can be properly accounted for. Mass thickness is expressed as the weight in pounds per square foot (psf) of a

* A convenient way of expressing the mass of a barrier is the *mass thickness* (X), which is nothing more than the unit weight of the barrier expressed in psf. Mass thickness for various common building materials are given in table XIII.

solid barrier. Table XIII shows some representative mass thicknesses.

f. Geometry Shielding. The second method of shielding is to increase the distance to the detector from the fallout field and/or reduce the extent of the fallout field contributing to the dose. To move the detector away from the source and barrier another mode of attenuation is accomplished. The main cause of this attenuation is not the mass thickness of the intervening air; the cause is the geometry involved. This geometry shielding considers the detector position relative to source and barrier; to the shape, extent and distribution effect of the barrier; and to the source.

*Table XIII. Brief Table of Mass Thicknesses**

This table is for guidance only. It may be assumed in general that the weights given for the various types of roof, floor, and wall construction as found in standard engineering tables are equivalent to the mass thickness of the construction. Publications of the American Standards Association, the American Institute of Steel Construction, the American Concrete Association, and others may be used for this purpose.

Item	Thickness		Weight (mass thickness)	
	in	mm	(lb/sq ft)	(gr/sq cm)
Asbestos:				
Board	3/16	4.76	2	0.97
Corrugated			4	1.95
Shingles	5/32	3.97	2	0.97
Asphalt:				
Roofing (3 ply)			1	0.49
Roofing (4 ply and gravel)			6	2.93
Shingles			2	0.97
Clay:				
Brick	1	25.4	8–10	3.9–4.9
Tile:				
Facing	4	101.6	25	12.2
Partition	6	152.4	28	13.6
Shingles			10–20	4.9–9.7
Structural	8	203.2	42	20.5
Concrete:				
Cinder	1	25.4	9	4.4
Reinforced	1	25.4	12½	6.1
Stone or gravel (std wt)	1	25.4	12–12½	5.8–6.1
Block (hollow)				
Stone or gravel (std wt)	6	152.4	42	20.5
Gypsum:				
Block	4	101.6	10–12	4.9–5.8
Plaster:				
Applied direct or on lath	½–¾	12.7–19.0	5–6	2.4–2.93
Plywood sheathing	⅜	9.5	1	0.49
Soil	1	25.4	6–10	2.93–4.9
Steel plate	1	25.4	41	20.0
Stone masonry	1	25.4	10–14	4.9–6.8
Wood siding	1	25.4	1–2½	0.49–1.22

* Mass thickness of concrete-joist floors and floors with deep or closely spaced beams can be taken as the average dead floor weight per square foot. The mass thickness of composite construction can be estimated by a weighted average of the relative percent contribution of each material. For expedience, dead floor weights tabulated in handbooks (such as the CRSI Handbook) are adequate approximations of the mass thickness, provided the associated beams and spans are of normal proportions.

(1) Consider the roof of a structure as both a limited primary source and a barrier as illustrated in figure 29. A detector close to the roof (fig. 28, *a* and *b*) will be a greater response than one placed farther away from the source area (a′ and b′). The detector actually "sees" the same roof area in each case, but the detector response is less when the source area subtends a smaller angle at the detector.

(2) Another aspect of geometry shielding occurs when the primary source is of infinite extent and a cleared area is caused by a building or structure. Figure 29 illustrates this idea.

(3) Shape of the structure also affects the detector response and can be easily demonstrated—a detector 10 feet (3 meters) out from the center of a wall will have one response if the wall is long and narrow and another if the wall is square, though subtending the same angle. Geometry shielding thus expresses all features of the structure configuration other than the absorption caused by interactions with wall material.

g. Combined Shielding. The effect obtained by combining barrier shielding and geometry shielding is called *combined shielding.* The

product of the roof barrier effect and the roof geometry effect gives the overall roof contribution (para 51). The product of the wall barrier effect and the ground geometry effect gives the overall ground contribution (paras 52 and 56).

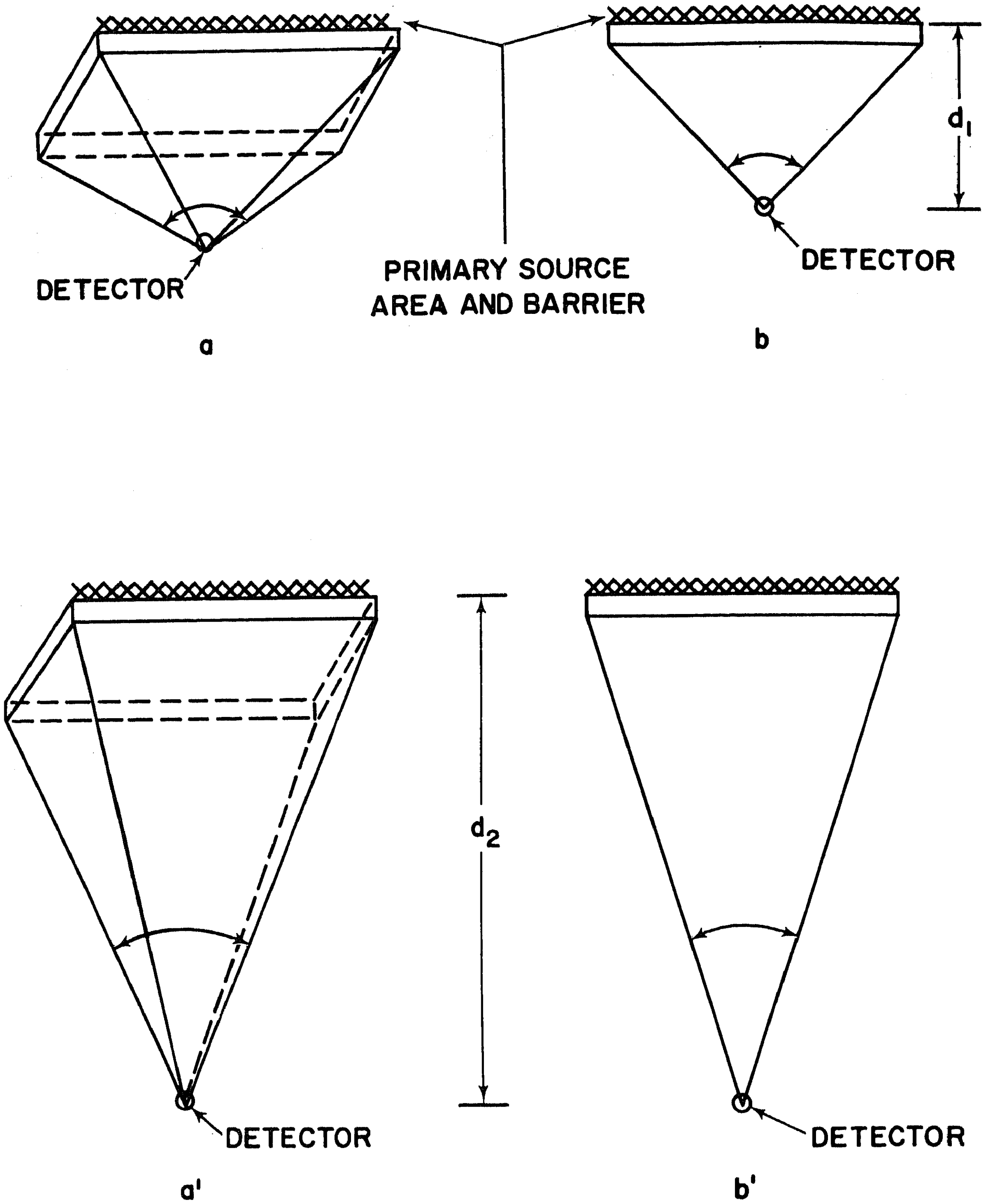


Figure 28. Geometry shielding.

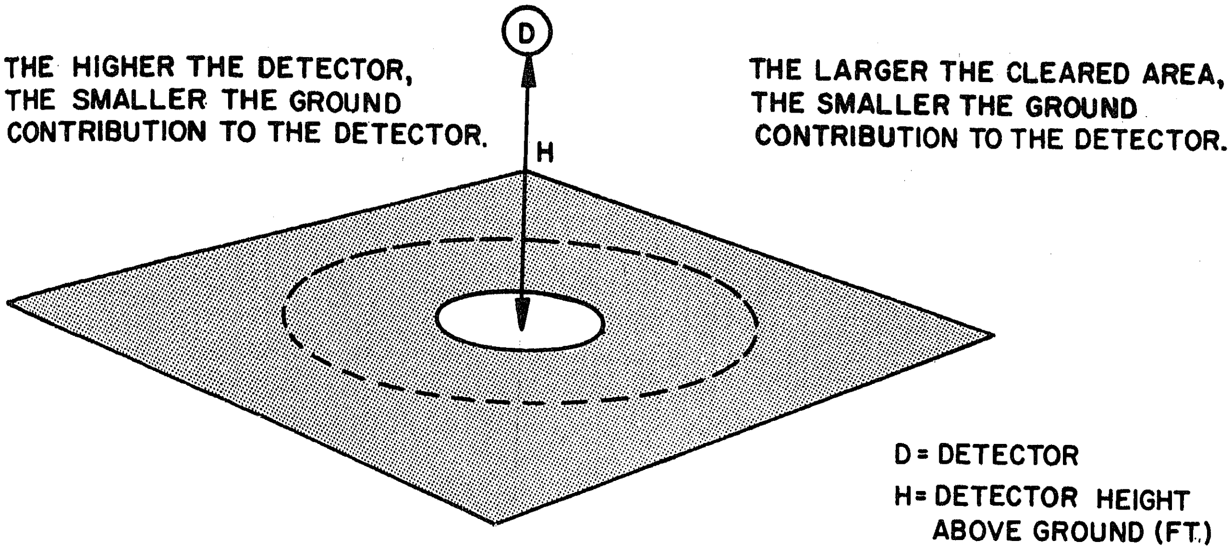


Figure 29. Ground contribution factors.

50. Protection Factor

a. Protection factor determination is the final objective of shielding analysis. The factor is an index of the shielding characteristics possessed by a structure with regard to the detector position. That is, it is a ratio of the amount of radiation that would be received by a person (or detector) in an unprotected location compared to the amount he would receive in his actual position within the structure. It is always an "overall" factor and cannot be obtained by the direct summation of its contributing elements.

b. The protection factor (P_f) is the reciprocal of the total reduction factor where R_f (total reduction factor) $=$ R_f (overhead) $+$ R_f (walls) $+$ R_f (other sources). In general, the total reduction factor is equal to the overhead contribution plus the ground contribution ($R_f = C_o + C_g$). *For example,* if the roof contribution to the detector (overhead reduction factor at this point is 0.015 and the ground contribution (wall reduction factor) at this point is 0.010, and there is no other contributing source, then the sum of these reduction factors (0.025) will be the total contribution to the detector, or the total reduction factor. If $P_f = 1/R_f$, the protection factor for this building would be 1/.025, or 40.

51. Roof Contribution

a. Fallout is generally assumed to cover roof surfaces uniformly according to their horizontal projections. For a building with no interior partitions, only three factors are necessary to determine the combined shielding effects for the room contribution (A, fig. 30) These factors are the plan area of the roof, the total overhead mass thickness, and the distance from the contaminated roof to the detector. Table XIII shows the mass thickness for various common building materials. First, it is necessary to know the total mass thick-

ness of the roof and of all the floors between the contamination and the detector, or the total overhead mass thickness (X_o), which is the sum of the mass thickness of the overhead barriers; second, the total area of the roof over the detector (A_r); and third, the distance from the detector to the roof (Z). The combined shielding effect of the roof contribution is found in the nomogram in figure 31.

Illustrative example 1. For buildings with no interior partitions (or partitions where mass thickness of the interior wall (X_i) < 10 psf), the roof contribution can be determined as shown below.

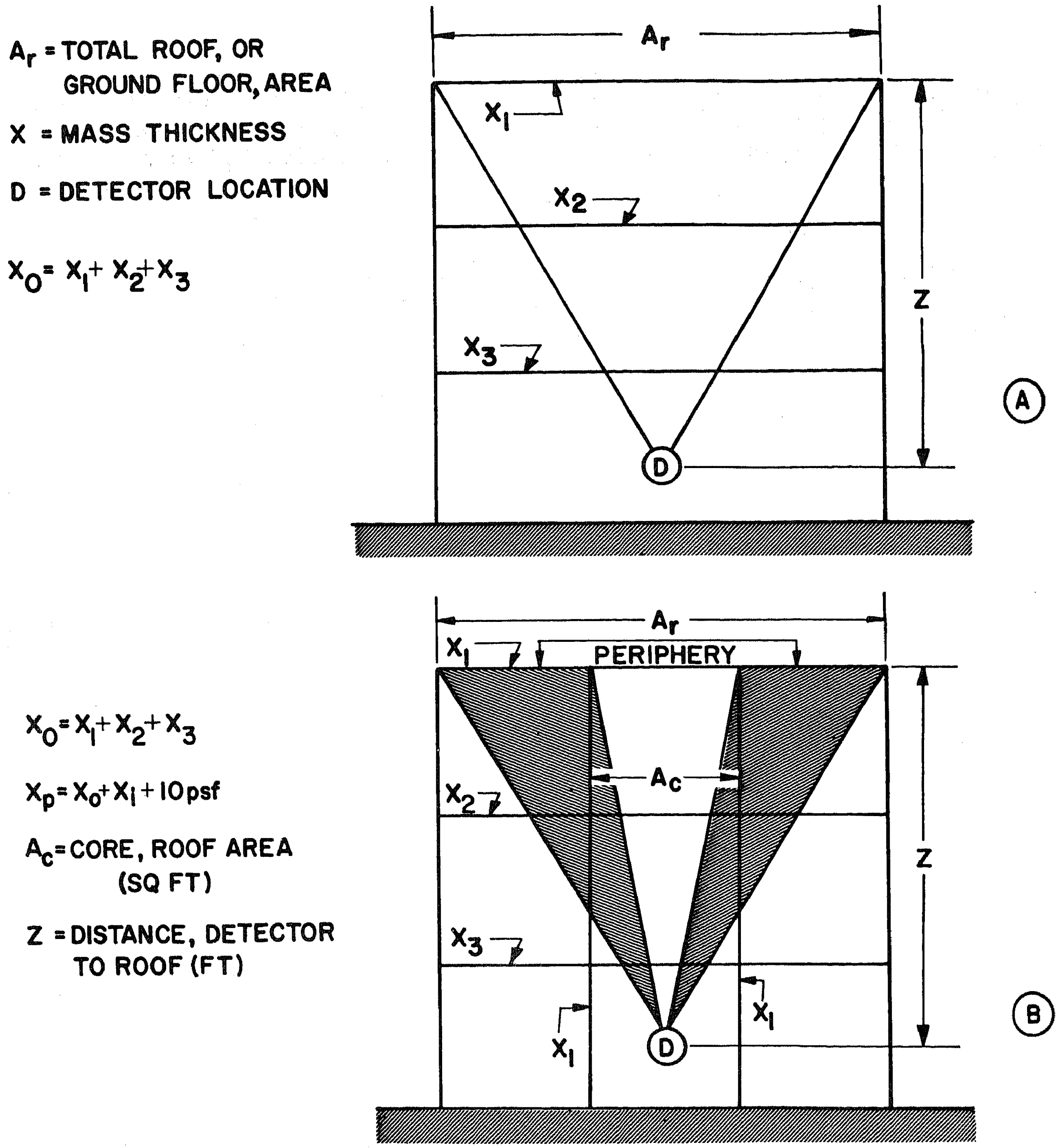


Figure 30. Roof contribution.

GIVEN: Detector on first floor of a 3-story building (fig. 32) with:

A_r = 5,000 sq ft
Z = 33 ft
X_o = 160 psf

FIND: Protection factor (P_f)

SOLUTION: Using A_r and Z as given above, N is found to be 0.94 from the nomogram in figure 31.
$X_o = X_r + X_f = 60 + 50 + 50 = 160$ psf.

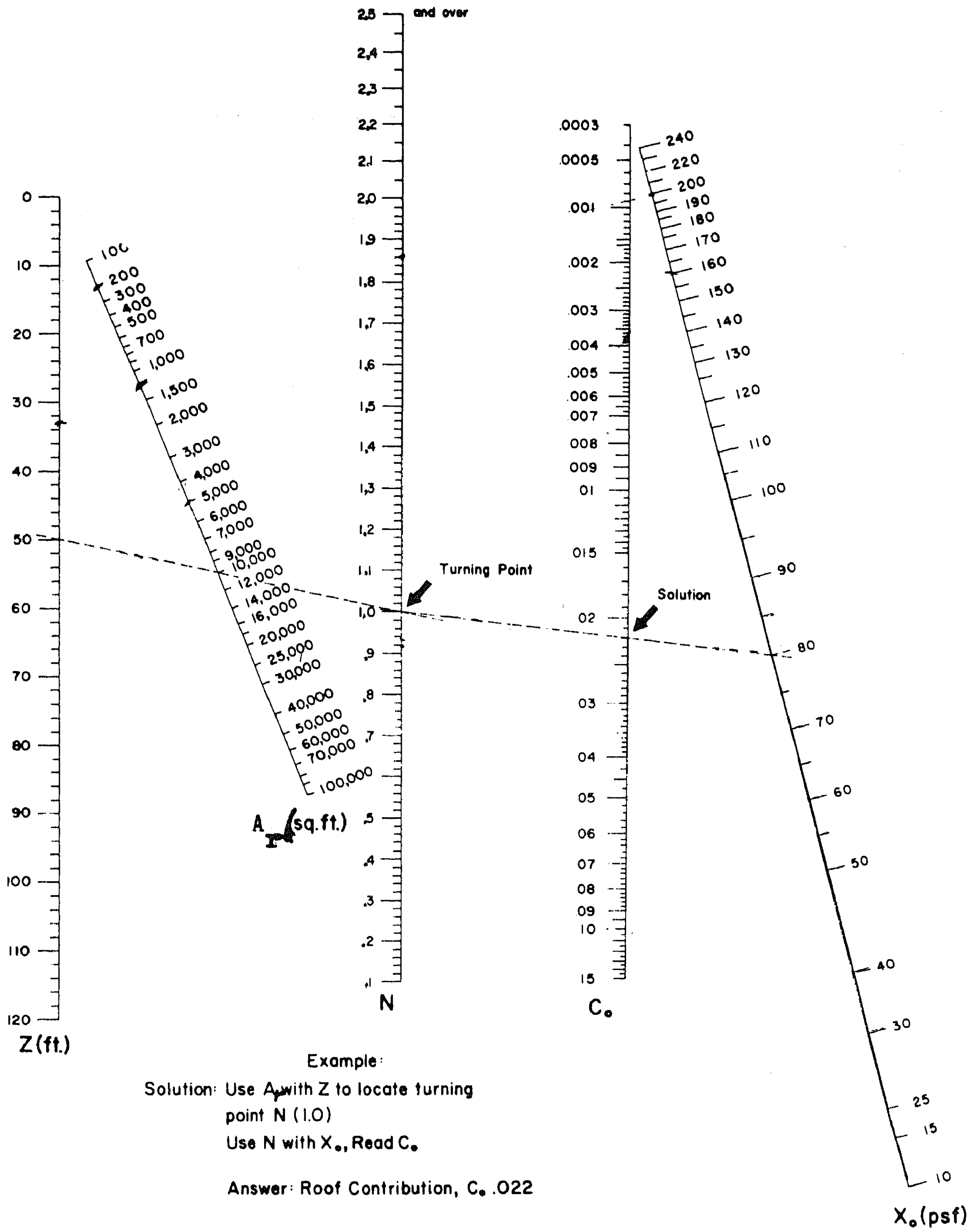


Figure 31. Nomogram–combined sheilding effects, roof contribution.

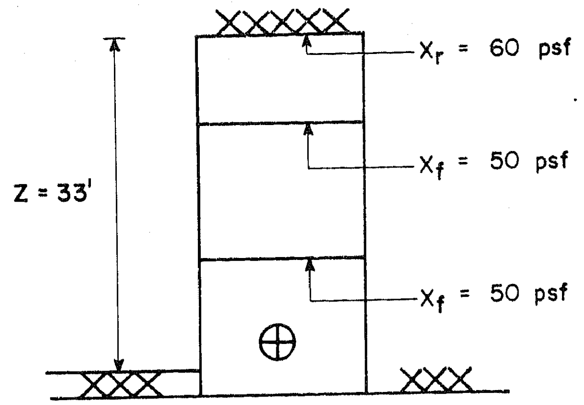


Figure 32. Roof contribution—no interior partitions.

Using N and X_o on the nomogram in figure 31, C_o is read at 0.0035.

If the ground contribution (C_g) is taken to be .024, and using the formula, $R_f = C_o + C_g$, then $R_f = 0.0035 + 0.024 = .0275$, and $P_f = 1/R_f = 1/.0275 = 36$.

b. In a building with interior wall partitions, the contribution from the central roof area, or core area enclosed by the interior wall, must be added to the contribution from the peripheral roof area, or that roof area which is outside the core area (B, fig. 30). This is done as follows: *The central roof area contribution* (C_c) is found (as above), using the core area (A_c) instead of the total roof area (A_r), the total overhead mass thickness (X_o), and the distance from the detector to the roof (Z) with the nomogram in figure 31.
The *peripheral roof area contribution* (C_p) is found by differencing two roof contribution readings: Assume the entire roof area (A_r) has a mass thickness $X_p = X_o + X_i + 10$ psf. Using this mass thickness (X_p) with A_r and Z, read the roof contribution from figure 31. Next, assume the core area has an overhead mass thickness $X_p = X_o + X_i + 10$ psf. Use X_p, A_c, and Z with figure 31 to find this roof contribution. Subtract the second reading from the first reading to find the peripheral roof area contribution (C_p). The total roof contribution is the sum of these reduction factors, or $C_o = C_c + C_p$.

Illustrative example 2.

GIVEN: The building in the drawing (fig. 33) has a core area 50′ x 25′, interior wall mass thickness (X_i) of 30 psf, and a total plan area of 5,000 sq ft.

FIND: Total roof contribution.

SOLUTION: For *central roof area contribution,* use the following:

A_c = 1,250 sq ft
Z = 33 ft
X_o = 160 psf

With these figures, N is found to be 1.86 (fig. 31) and the core roof contribution, or $C_c = .0022$. For the *peripheral roof area contribution,* assume the entire roof area has an effective mass thickness of $X_p = X_o$ (total overhead mass thickness) $+ X_i$ (mass thickness of interior wall) + 10 psf. Using A_c and Z as given above, and X_p to be $160 + 30 + 10 = 200$ psf, the nomogram in figure 31 shows N to be 1.86. With N = 1.86, and $X_p = 200$ psf, $C_c' = .0009$ (fig. 31), taking A_r = 5,000 sq ft (from illustrative example 1), Z = 33 ft, and $X_p = 200$ psf (as determined above), figure 31 shows N to be .94. Then $C_r = .0014$ (fig. 31). The peripheral roof area contribution, therefore, is $C_p = C_r - C_c' = .0014 - .0009 = .0005$.

Total roof contribution is $C_o = C_c + C_p = .0022 + .0005 = .0027$.

Note. Decontaminated Roofs. Skyshine, an effect produced by scattering of radiation by the air, has been accounted for in roof contribution readings in figure 31. If a roof is decontaminated by a washdown system, skyshine is still a factor to be considered. Table XIV shows the skyshine correction in roof contribution for a decontaminated roof.

52. Ground Contribution (Aboveground Areas)

a. Ground contribution is radiation starting from a source on the ground and going through the walls to the detector. It must penetrate walls, windows, and doors before reaching the detector (D, fig. 34). Generally a distinction is made between the radiation passing through walls and that passing through apertures.

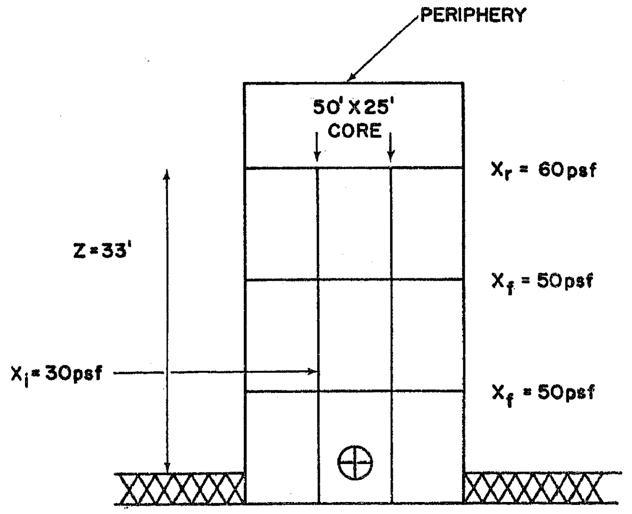


Figure 33. Roof contribution—with interior partitions.

Table XIV. Skyshine Correction in Roof Contribution for Decontaminated Roof

Total overhead mass thickness, X_o	Correction factor
0	0.15
50	0.08
100	0.04
200	0.01

The roof contribution found in figure 31 is multiplied by the above correction factor to determine the overhead contribution, that is, the effect of sykshine through the decontaminated roof.

b. In a windowless structure, radiation reaches the detector both directly and by scattering within the walls. These barrier effects are accounted for in the wall thickness scale (X_w) in figure 35. The geometry effects are related to the cleared area around the detector, which is given as the plan area (illustrative example 3, below). If the building has no interior partitions, the wall mass thickness, X_w, equals the exterior wall mass thickness, X_e. However, when the interior partitions exist, the wall mass thickness used for the nomogram (fig. 35) should be the sum of the exterior and interior walls, that is, $X_w = X_e + X_i$. (See illustrative example 4, par. 54). For compartment geometries with corridor wall thickness X_c and divider partition thickness X_d as in figure 36, the interior wall mass thickness X_i is to be taken as $X_i = \frac{X_d}{2} + X_c$.

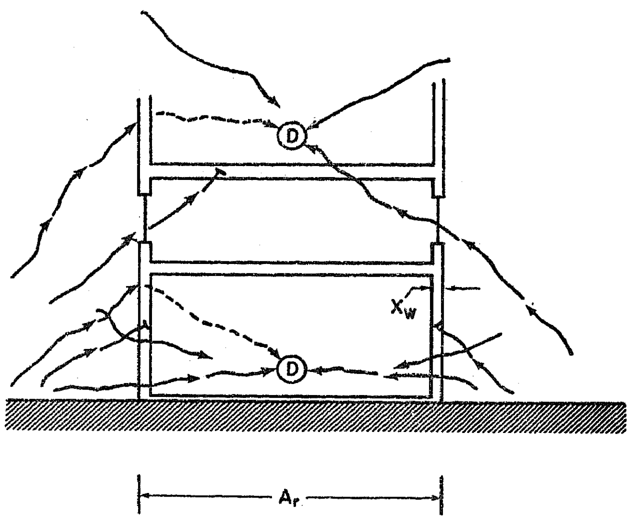


Figure 34. Ground contribution—aboveground areas.

Illustrative example 3. For buildings with no apertures and no interior partitions, only the area of the building (A_r) and the wall mass thickness (X_w) need be known to read the ground contribution to the first floor detector.

(1) With no partitions:

GIVEN: $A_r = 10{,}000$ sq ft, $X_w = 48$ psf

FIND: Total ground contribution to a first floor detector

SOLUTION: Using $A = 10{,}000$ sq ft, and $X_w = 48$ psf, then $C_g = .091$ (fig. 35)

(2) With interior partitions:

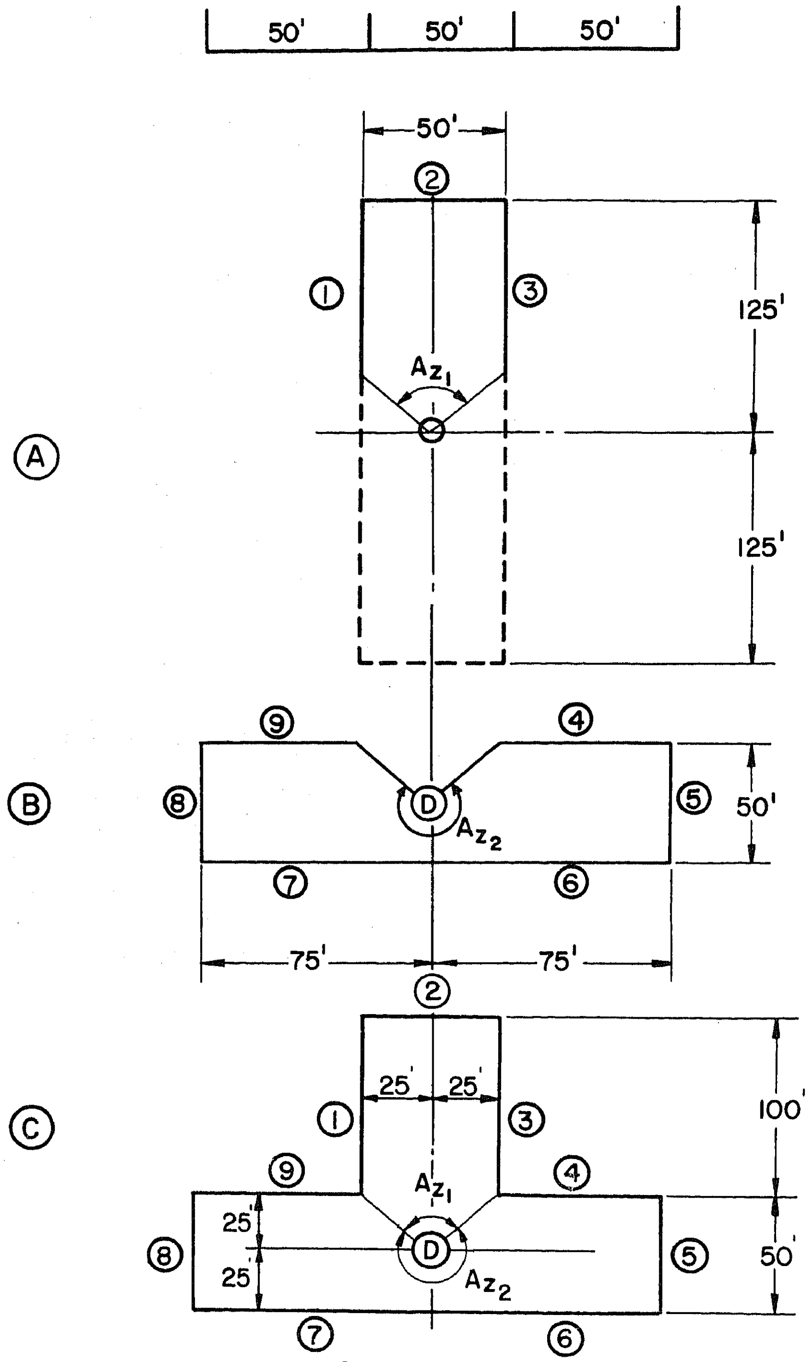
GIVEN: $A_r = 10{,}000$ sq ft, $X_w = 48$ psf, and $X_i = 15$ psf

FIND: Total ground contribution to a first floor detector

SOLUTION: Using $A = 10{,}000$ sq ft, and $X_w = (48 + 15)$ psf $= 63$ psf. Then $C_g' = .065$ (fig. 35)

53. Azimuthal Sectors

a. Reduction factors for ground contribution may be calculated on a wall-by-wall basis, provided adjustments are made for the relative



(Cg FROM FICTITIOUS BUILDING Ⓐ) A_{z_1} + (Cg FROM FICTITIOUS BUILDING Ⓑ) A_{z_2} =
Cg OF REAL STRUCTURE Ⓒ

NOTE: ALL THE WALLS IN FICTITIOUS BUILDINGS Ⓐ AND Ⓑ ARE OF THE SAME MATERIAL (MASS THICKNESS) AND LIE IN EXACTLY THE SAME ORIENTATION TO THE DETECTOR AS THEY ARE IN THE REAL STRUCTURE Ⓒ. EACH PARTITION OF THE FICTITIOUS BUILDING IS TREATED AS A SEPARATE RECTANGULAR STRUCTURE THAT IS SYMMETRIC ABOUT THE DETECTOR POSITION.

Figure 37. Azimuthal sectors.

FIND: Total ground contribution

SOLUTION: Using A = 10,000 sq ft and X_w = (100 + 30) psf, read (on fig. 35) $C_g' = .0142$

Using A = 10,000 sq ft and X_w = (0 + 30) psf, read $C_g' = .144$

$C_g = .0142\ (1 - A_p) + .144\ (A_p) = .0142\ (1 - .30) + .144\ (.30) = .05314.$

b. Many large buildings, which are otherwise rather massive, have windows extending entirely across one wall (B, fig. 38). This is a situation where a ground floor detector is located above sill level. The nomogram in figure 35 will give the two readings necessary to account for the solid wall contribution and the aperture contribution. First, assuming the wall

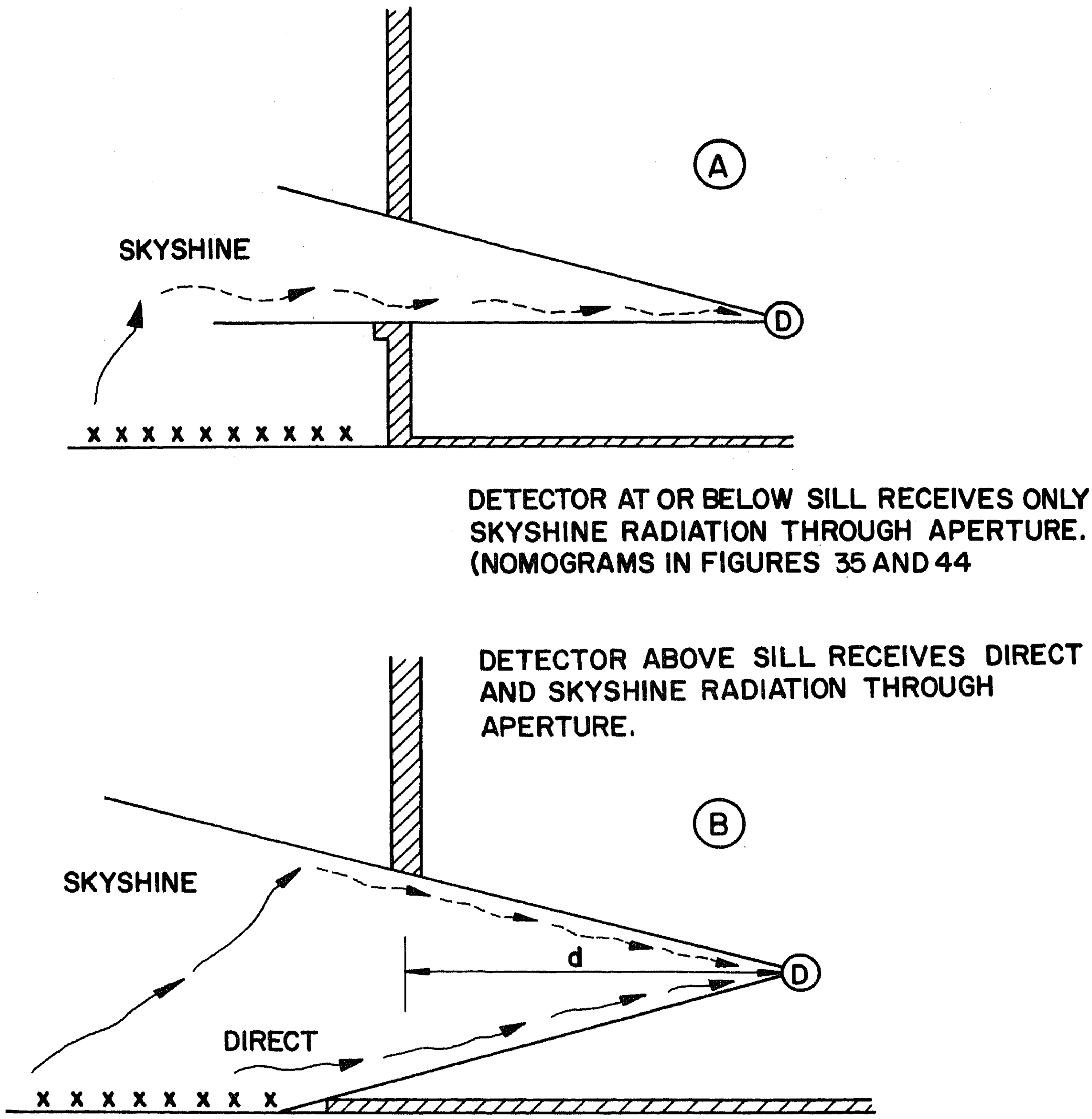


Figure 38. Aperture contributions.

is solid, use A with $X_w = X_e$ and get a reading on the nomogram in figure 35. Then assuming the building is made entirely of glass, use A with $X_w = 0$ psf to get a reading. These two ground contributions (C_g') are then summed according to their respective azimuthal sectors.

Illustrative example 5.

GIVEN: $A_r = 100' \times 80' = 8{,}000$ sq ft; first story detector, $X_e = 80$ psf in all but 40 feet of the perimeter of the building; the 40 feet consist of floor-to-ceiling windows (fig. 39).

FIND: Total ground contribution

SOLUTION:

(1) Solid wall—$A_r = 8{,}000$ sq ft and $X_e = 80$ psf
Solid wall $C_g = .0495$ (fig. 35)

(2) Glass wall—$A_r = 8{,}000$ sq ft and $X_w = 0$ psf

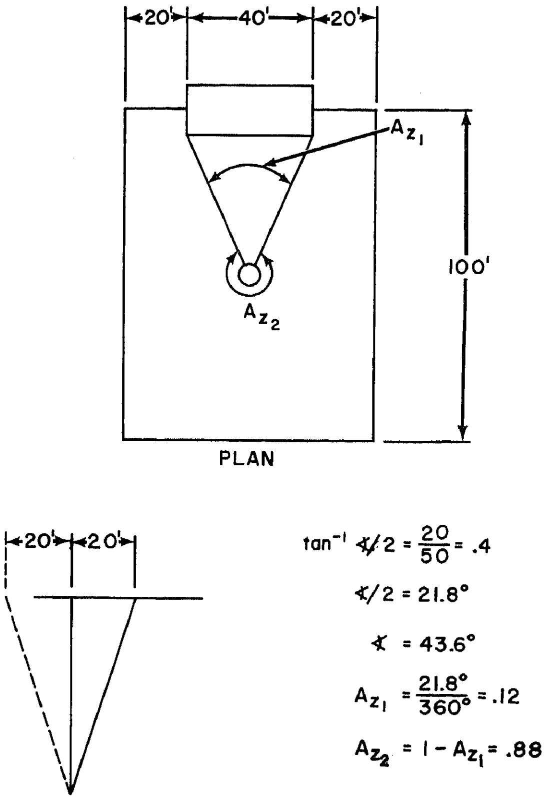


Figure 39. Ground contribution—with windows and apertures.

Glass wall $C_g = .324$ (fig. 35)

$$\text{Total } C_g = C_g' \text{ (glass) } A_{z_1} + C_g \text{ (solid wall) } A_{z_2}$$
$$= (.324)\ (.12) + (.0495)\ (.88)$$
$$= .039 + .0435 = .082$$

Illustrative example 6. For upper detector locations, the first story ground contribution (C_g), reading from figure 35, i multiplied by the height correction factor from table I (fig. 35) to obtain the total ground contribution.

GIVEN: $C_g = .091$ and the detector height above ground (H) = 40 ft

FIND: Total ground contribution

SOLUTION: Read H_c (40) = .54 (from table I, fig. 35)
$C_g = (.091)\ (.54) = .049$

Illustrative example 7. First story apertures are handled as in illustrative examples 4 and 5 para 54). (Ignore apertures when $X_e \leq 50$ psf. For basement wall aperture contribution, ignore apertures if basement wall ≤ 50 psf. If $X_b > 50$ psf handle as in illustrative examples 4 and 5.)

55. Mutual Shielding and Height Effects

Adjacent buildings may effectively reduce the amount of radiation reaching a detector from ground contamination (mutual shielding effect), and upper floors of multistory buildings may offer substantial protection from fallout (height effect) (fig. 40). Nomogram (fig 43) and table 1 (fig. 35) give correction factors for these two effects.

a. For upper story detector locations where no adjacent buildings shield the detector from ground contamination (A, fig. 40), the simple height correction factor (H_c)* is applied to the aboveground contribution (C_g'). For solution to a problem, see illustrative example 6 (para 54).

b. To account for the shielding of buildings within 300 feet (91 m), a mutual shielding correction factor (MS)** is applied to the

* H_c, height correction factor; is determined from table I in figure 35.

** MS, mutual shielding correction factor is determined from nomogram in figure 41.

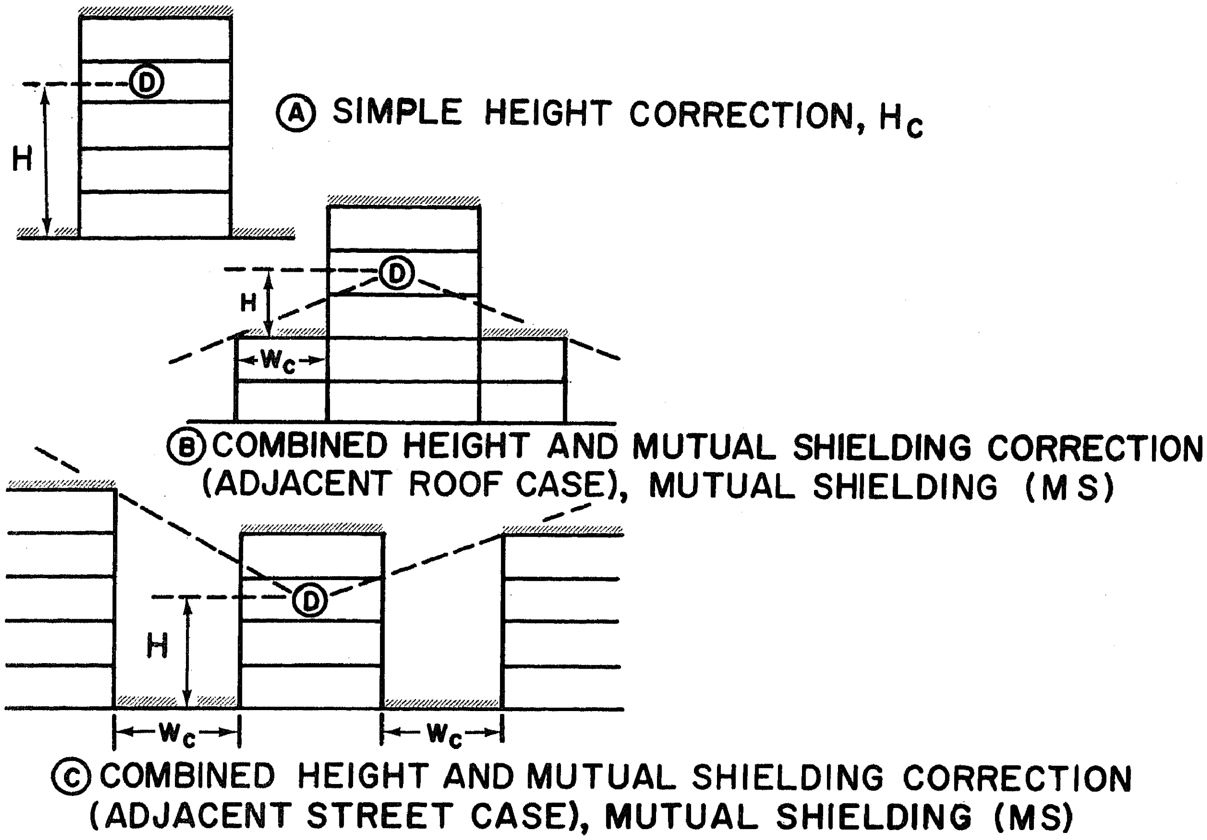


Figure 40. Height and mutual shielding effects.

aboveground contribution. Discretion must be used when selecting the appropriate height of the detector above the source field because adjacent roofs can complicate matters (B, and C, fig. 40). This mutual shielding factor is read from the nomogram in figure 41, using the width of a rectangular strip of contamination (W_c) and the height of the detector above the contaminated plane (H).

Illustrative example 8. The nomogram in figure 41 is used only when $W_c \leq 300$ ft. The mutual shielding (or limited strip) correction factor (MS) accounts for both the height of the detector above the source plane and the width of the rectangular strip of contamination surrounding the building. Consider floors up to 50 psf (24.4 gr/sq cm) as "thin" and those over 50 psf as "thick."

GIVEN: $A_r = 10{,}000$ sq ft, H = 3 ft, $X_e = 48$ psf, and $W_c = 40$ ft

FIND: Mutual shielding correction factor and effect on ground contribution

SOLUTION: Using case A in the nomogram in figure 41, the MS is determined to be .6

$C_g' = .091$ (illustrative example 3, para 52)

$C_g = .091 \times .6 = .055$

Illustrative example 9. When only a part of a building is shielded from ground contribution by another structure, the height correction factor (H_c) should be added to the mutual shielding correction factor (MS) according to the azimuthal sectors of the unshielded and shielded sections (fig. 42).

Case A - Upper Stories, Thin Floors ($X_f \leq 50$ psf), and First Story, Thin or Thick Floors.

Case B - Upper Stories, Thick Floors ($X_f > 50$ psf)

Example

First Story Detector, H=3ft.,
W_c = 100 ft.
Use Case A
Solution: MS = .825

Fourth Story Detector, H=40 ft.,
X_f=80psf, W_c = 60 ft.
Use Case B
Solution: MS = .025

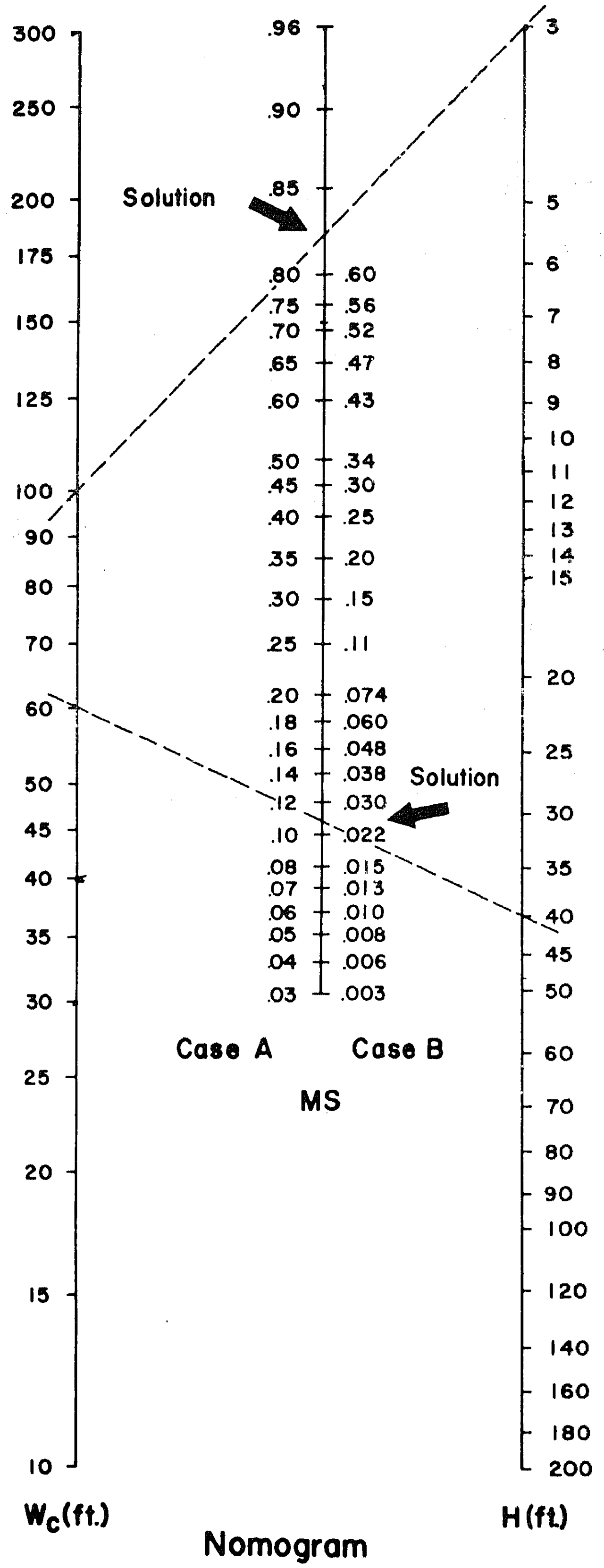
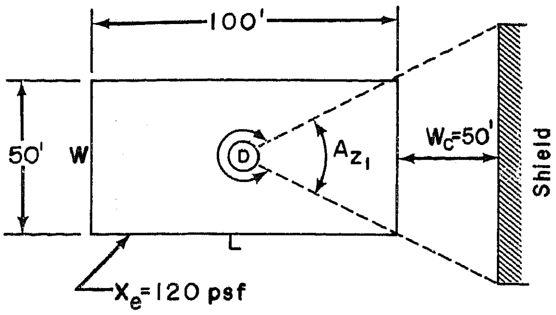


Figure 41. Nomogram—MS, fraction of first-story infinite field dose from a finite rectangular field.



A_{Z_1} (Shielded)...

$\tan^{-1} \angle/2 = 25/50 = .5$

$\angle/2 = 26.6°$

$\angle = 53.2°$

$A_{Z_1} = 53.2/360 = .148$

$A_{Z_2} = 1 - A_{Z_1} = .852$

Figure 42. Shielding.

GIVEN: A_r = 100 ft × 50 ft = 5,000 sq ft, X_e = 120 psf, X_f = 60 psf, W_c = 30 ft on 50-foot end of building (balance of building unshielded), and H = 15 ft

FIND: Mutual shielding correction factor and effect on ground contribution

SOLUTION: H_c in table I (fig. 35) = .73
Using the nomogram in figure 41, case B (upper story, thick floor case), with W_c reading 30 ft and H reading 15 ft, MS is determined to be .042.
A = 5,000 sq ft, X_w = X_e = 120 psf, and C_g' = .0245 (from fig. 35).
(.148) (.042) + (.852) (.73) = .628
C_g = (.62) (.0245) = .015

c. In the uncommon case where the strip of contamination is limited but exceeds 300 ft (91 m), then for upper story detector locations, the correction factor (1–H_c (W_c)) as a multiplier of ground contribution gives a good estimate of the ground contribution.

Note. From the nomogram in figure 41, for first-story detector locations, MS = .96, where W_c = 300 ft.

Illustrative example 10. First story detectors receive most of their ground radiation from contamination within a 300-foot wide strip (see nomogram in figure 41, reading for H = 3′ and W_c = 300′), but if W_c is limited and yet exceeds 300 ft, an approximation of the shielding effect of this limited source area can be found with the correction factor (1–H_c (W_c)), where H_c is read from table I (fig. 35).
GIVEN: Upper story detector, W_c = 400 ft
FIND: Total ground contribution
SOLUTION: H_c (400′) = .14
MS = (1—.14) = .86
C_g = .86 C_g

56. Ground Contribution (Belowground Areas)

In basement areas with virtually none of their walls exposed above grade (fig. 43), the only radiation reaching a detector from ground contribution would be that scattered by the walls on the ground floor, or skyshine through the walls. All of this radiation must pass through the floor immediately above the basement (X_δ).

a. For the simplest case, with windowless walls on the ground floor, figure 44 gives the reduction factor for radiation scattered into a detector at the center of a basement, 5 feet (1.5 m) below the ground floor. Only two values are needed to enter the nomogram in figure

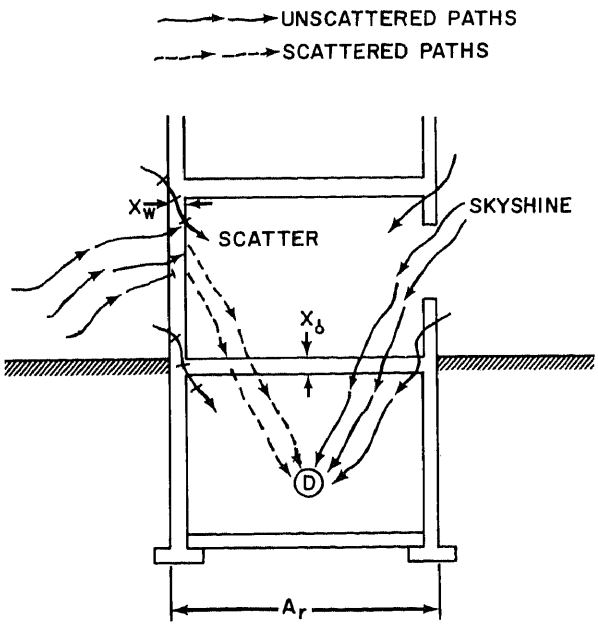


Figure 43. Ground contribution—belowground area.

Table II

MULTIPLIER FOR BASEMENT EXPOSURE (K_b)

Area sq. ft.	Exposed basement in feet 1'	2'	3'	4'	5'*
up to 400	.35	.70	1.05	1.40	1.75
1000	.32	.64	.96	1.28	1.60
2000	.28	.55	.83	1.10	1.38
3000	.24	.47	.71	.95	1.19
4000	.21	.42	.63	.84	1.05
5000	.19	.38	.57	.76	.95
6000	.18	.35	.53	.70	.88
7000	.17	.33	.50	.66	.83
8000	.16	.31	.47	.63	.79
9000	.15	.31	.46	.61	.77
10000 or over	.15	.30	.45	.60	.75

Detector position is assumed to be below sill level

Example:

Wall Mass Thickness, X_w	80 psf
Immediate Overhead Mass Thickness, X'_o	50 psf
Solution: Ground Contribution, C_g	.00146

*For exposures which put detector above ground level, use Nomogram in figure 35

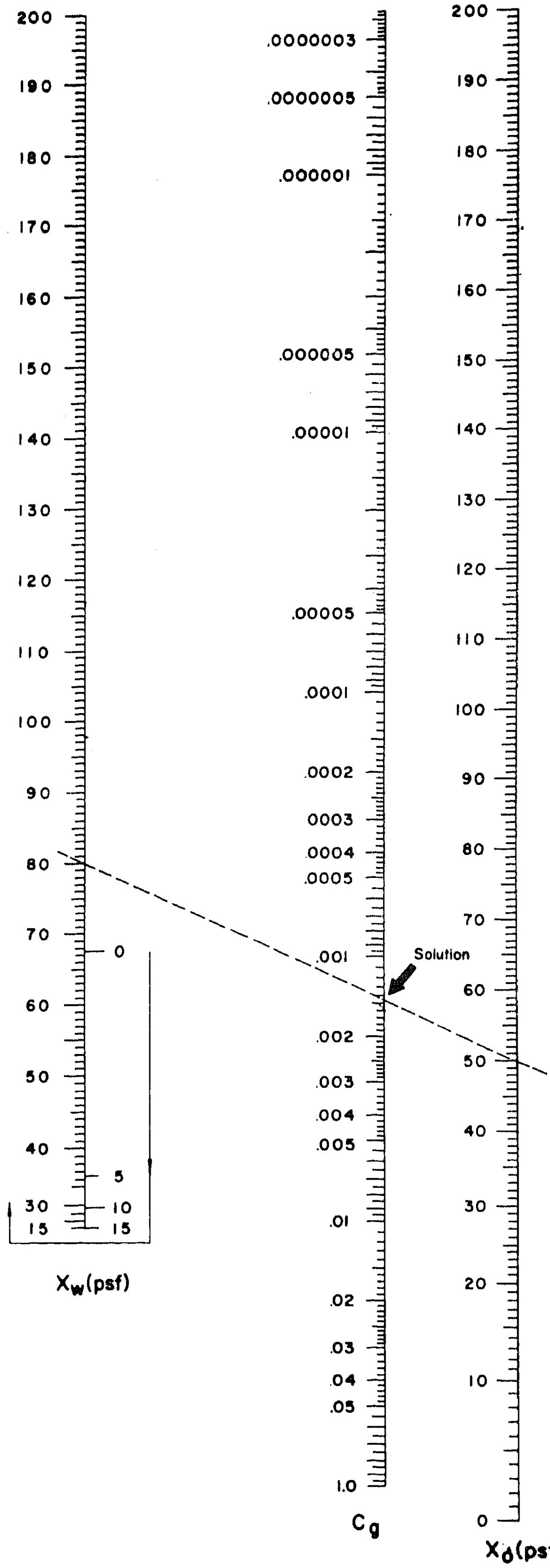


Figure 44. Nomogram—combined shileding effects, ground contribution, belowground area.

38: the mass thickness of the floor walls (X_w) and the mass thickness of the ground floor (X_o'). It should be noted here that for basement areas between 400 and 14,000 sq ft (37 and 1,300 sq m), there is no appreciable geometry shielding effect on the radiation that scatters in and down, and thus no area scale appears in figure 44.

Illustrative example 11.
GIVEN: $A_r = 8{,}000$ sq ft, $X_e = X_w = 96$ psf, and $X_o' = 40$ psf
FIND: Belowground area contribution
SOLUTION: From figure 44 (ignore area), read $C_g' = .0017$

b. To account for the contribution to a basement detector through exposed but windowless basement walls, the belowground area contribution is obtained from figure 44, using $X_w = X_b$, with $X_o' = 0$ psf. (Partitions in the basement are added to the basement wall and this total mass thickness is the X_b to be used in figure 44. The ground contribution (C_g') thus found is multiplied by the correction factor for basement exposure (K_b) found in table II (fig. 44). Thus the total ground contribution when basement walls are partially exposed equals the sum of the first story contribution and the contribution through the exposed basement walls.

Illustrative example 12.
GIVEN: $A_r = 8{,}000$ sq ft, $X_e = 50$ psf, basement 8 feet deep and exposed 3 feet above ground level, $X_b = 80$ psf, and $X_o' = 15$ psf (fig. 45)
FIND: Total ground contribution
SOLUTION: For first story contribution, $X_e = 50$ psf and $X_o' = 15$ psf
On nomogram (fig. 44), read $C_g = .013$
For basement wall contribution, $X_b = 80$ psf, and $X_o = 0$ psf
On nomogram (fig. 44), read $C_g' = .0235$
For 3-foot exposure, where $A = 8{,}000$ sq ft, $K_b = .47$ table II, fig. 44)
Basement wall contribution $= .47 \times .0235 = .011$
Total ground contribution, $C_g = .013 + .011 = .024$

57. Horizontal Passageways

The nomogram in figure 46 has been calculated to account for horizontal passageway detector readings. The passageway is assumed to be open at one end, with an infinite plane of contamination outside the passageway. The height of the opening is assumed to be 10 feet, and the nomogram is entered with the width of the opening (W) and the distance (d) of the detector from the opening. (An adjustment can be made for additional height of opening by increasing d 1 percent for each 2 feet of additional height.) The nomogram reading (R_f) gives the contribution to a detector 3 feet above the ground level of the passageway.

Illustrative example 13. To find the ground contribution into horizontal passageways (with one end open), enter the nomogram

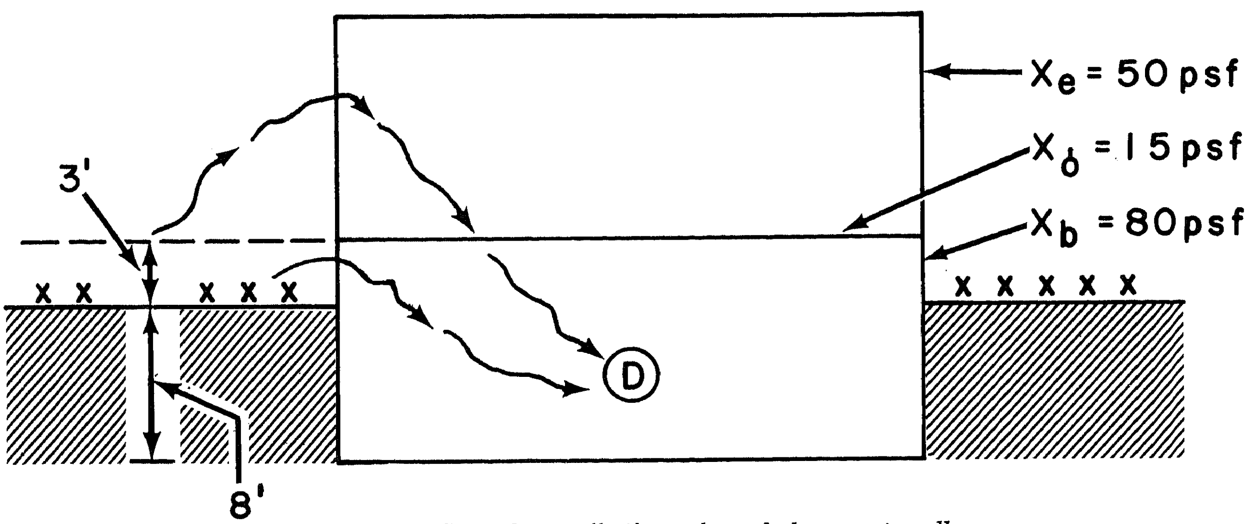


Figure 45. Ground contribution—through basement walls.

in figure 46 with the width of the opening (W) in feet, and the distance of the detector from the opening (d) in feet.
GIVEN:

(1) Height of opening = 10 ft, W = 10 ft, and d = 100 ft
(2) Height of opening = 15 ft, W = 30 ft, and d = 200 ft

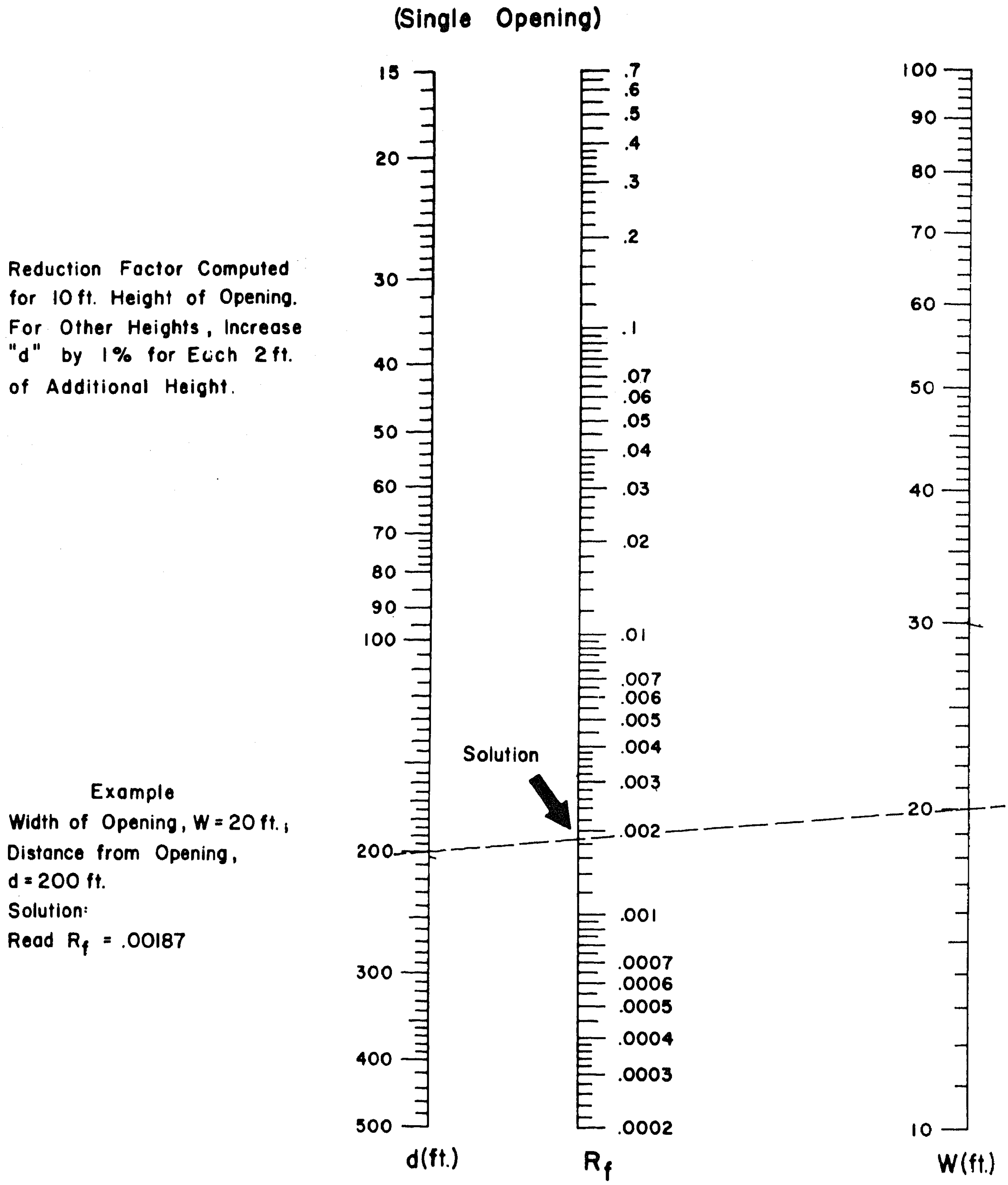


Figure 46. Nomogram—horizontal passageways.

FIND: Contribution into an isolated horizontal passageway

SOLUTION:

(1) From nomogram (fig. 46), read .0032

(2) Since the height of opening is 15 feet, it is necessary to increase d by 1 percent for each 2 feet above 10 feet. Therefore, multiply 200 by .025 and add to the 200 feet. This is computed as 205 feet. From the nomogram (fig. 46), read .0028.

CHAPTER 3

EXPEDIENT SHELTERS, INCLUDING USE OF EXISTING FACILITIES

Section I. INTRODUCTION

58. Existing Facility Utilization Concepts

a. As a good rule, it will not always be economically or logistically feasible to provide new and originally designed shelters. Also, in many instances, availability of time, personnel, and material will preclude the construction of new shelters. Because of these complexities, development of new structures specifically for shelters must be limited to the most vital functions and services.

b. To increase the number of shelters that can be made available, modification of certain existing facilities or substructures thereof to provide the desired protection against effects of nuclear, conventional, and chemical and biological weapons should be considered. Existing facilities can be categorized into conventional buildings, permanent fortifications, mines, tunnels, and caves.

c. Because the specific protection requirements for exclusion of chemical and biological agents remain the same, regardless of other factors, reference should be made to chapter 4 for feasibility, capabilities, and limitations of providing the additional CB capability to existing structures.

59. General Problems and Considerations Involved in Selection of Existing Structures

a. Strength Determination. The determination of the structural strength of an existing facility subject to blast loads is complex and difficult. At best, only an approximation can be made in the structural analysis of the facility.

b. Limitations. The choice of existing facilities is limited by the requirement for dispersion in nuclear warfare. The facility selected for use as a protective shelter must be located at some distance away from any likely nuclear attack targets.

c. Effects of Unknown Yield of Nuclear Weapons. There will always be some uncertainty about the yield of the enemy nuclear weapons. A certain degree of protection can be provided by protective shelters; however, complete assurance of protection against nuclear effects cannot be given.

d. Feasible Modifications. Feasible structural modification of an existing facility will increase the strength to no more than five times its original strength. In many cases this will not provide adequate protection against nuclear effects.

Section II. CONVENTIONAL BUILDINGS

60. Conventional Buildings with Shelter Potential

a. Types. The types of conventional buildings with a shelter potential are—

(1) Single-story, wooden structure with basement.

(2) Single-story, reinforced-concrete structure with or without basement.

(3) Single-story, steel frame structure with basement.

b. Criteria. In designing conventional buildings to resist the effects of a nuclear explosion,

relatively little data is available, and an exact design basis is difficult to establish. To try to balance the resistance of a building to meet all the hazards resulting from a nuclear explosion, it would be necessary to assume a specific bomb size, an exact location of the building relative to GZ, and particular climatic conditions.

61. Selection of Conventional Buildings

a. Vulnerability to Nuclear Effects. Buildings which are least vulnerable to nuclear effects should be selected. Some of the buildings are those that are located in an area where there is no danger from flying debris and fires from adjacent structures; away from congested areas where the accessibility of the structure may be denied by rubble, fire, or civilian and military personnel movement; at some distance from probable target areas, such as highly industrialized complexes and fuel refinery areas; and in an area where the radiation-shielding features of terrain are better utilized. Multistory buildings should be avoided because of the uncertainty of their structural strength and the great amount of debris that would result from their collapse.

b. Protective Measures.

(1) Recall that a large proportion of the energy of a nuclear explosion is released as thermal radiation, which, because of its speed of travel, is the first effect to reach the area surrounding GZ. The heat intensity will not be sufficient to ignite conventional structures in the fringe areas, but there is a fire hazard because of flammable materials lying around the immediate area as well as in the interiors of houses. Ignition of such materials could spread to the structures. Materials of that type could be ignited by the blast wave, which might upset furnaces, cause electrical short circuits, and break gas lines.

(2) Generally, the design of a residence less vulnerable to thermal effects should follow some simple rules to limit combustion and the spread of fires. Materials that will not burn readily should be used on exposed surfaces of the exterior. Exposed flammable materials should be shielded by barriers that will attenuate or reflect the thermal wave. The structure should be isolated from other elements with low ignition points wherever possible, otherwise, physical barriers should be erected.

(3) General statements can be made about strengthening a conventional building to resist blast effects. Such guides apply chiefly to the structure and cannot guarantee protection for the inhabitants. At moderate expense, conventional buildings can be strengthened to resist 5 psi (351.5 grams/sq cm) overpressure. Overpressure below this level (5 psi) are not generally fatal, but their secondary effects are hazardous. For example, even at less than 1 psi (70.3 gr/sq cm), shattered glass and flying debris present a problem that should be considered when reinforcing conventional buildings. Tables XV and XVI give hazardous overpressures.

(4) Blast resistance in conventional buildings can be increased by using ductile

Table XV. Overpressures for Severe Damage

		psi	*gr/sq cm*
1	One-story wood frame rambler type	0.5	35.15
2	One-story house with precast lightweight concrete walls, partitions and roof panels, aseismic design	5	351.54
3	Single-story, light-steel frame industrial building	2.2	154.67
4	Single-story, medium-steel, frame industrial building	2.3	161.70
5	Single-story heavy steel frame industrial building	2.5	175.77

Table XVI. Overpressures for Shattering Blast-Sensitive Elements

		psi	*gr/sq cm*
1	Glass windows, large and small	0.5–1.0	35.15–70.31
2	Corrugated asbestos siding	1.0–2.0	70.31–140.62
3	Corrugated steel or aluminum paneling	1.0–2.0	70.31–140.62
4	Wood siding panels, standard house construction	1.0–2.0	70.31–140.62
5	Concrete or cinder block wall panels, 8″ or 12″ thick, not reinforced	2.0–3.0	140.62–210.92

(rather than brittle) materials for structural parts. Steel reinforcement should be used in concrete and masonry. More rigid joints and connections reduce deflections.

(5) Usually fallout protection cannot be obtained in a conventional building without erecting additional massive walls and overhead barriers. Radioactivity does not affect the materials, but it is harmful to human beings. A good solution is to provide protective areas within a structure and to locate the structure at a maximum distance from probable sources of contamination. The lowest story of the building should be the shelter location, with the corners of basements as superior locations. If a building must be located nearer to sources of contamination, barrier shielding should be used. Radiation intensity is reduced by a mass of material. Such materials as steel, concrete, or masonry are more effective than wood. A sufficient thickness of material can reduce the exposure dose to a safe level.

(6) Natural protection factors and landscaping are significant in reducing vulnerability of a building to nuclear effects. Siting a house behind a hill reduces the blast force received from overpressures and winds. Grading may be used as a shield against fallout. Location near a lake or river is advised because water provides a self-decontaminating surface. Trees can provide a thermal shield. Paved terraces and drives can be decontaminated relatively easily.

(7) Other information on shielding is given in chapter 2.

62. Recommendations

a. Choice of Structures. The structures that best resist the effects of a nuclear explosion are heavily framed steel and reinforced concrete buildings. Least resistant are those having light frames and long spans of unsupported beams. The resistance to blast of brick structures in which walls support a load is poor. The effect of shape is not very pronounced in conventional structures of rectangular form. Flat surfaces such as windows in an extensive wall surface will have no rapid relief of pressure except by breakage. The columns in rectangular frame structures are generally oriented with the stronger axes parallel to the long dimension of the building. To provide greater resistance to blast loads, these columns should be oriented with the stronger axis perpendicular to the long side.

b. Venting. Venting of adjacent spaces results in more or less equilization of the pressures on either side of partitions. With a sturdy frame and light, breakable panels in the exterior walls, partitions, and roof, a building is difficult to damage seriously because a blast strips the panels from the frame with little force on the frame itself. If venting cannot be done, the frame and panels must withstand large pressure loads or be damaged. The damage to partitions is often not serious, but damage to floor slabs may require attention.

63. Improvement Procedures for Existing Basements

a. Introduction. The procedures explained in the following paragraph are an expedient means of analyzing and/or selecting improvements for an existing basement for use as a low overpressure blast shelter. Figures 47 and 48 show typical basement roof framing systems. An upper limit of 15 psi (1 kg/sq cm) is the maximum overpressure for which a shelter could be improvised. Further, the use of the nomograms within the context of this procedure is limited to the assumptions and recommendations outlined in *b* below.

b. Assumptions and Limitations. In the procedures discussed here, the following conditions must be taken into consideration:

(1) All spans are assumed to be simply supported.

(2) Loading is based on the peak overpressure applied as a static load.

(3) No consideration is given to the impact loading which might result from falling structural elements and debris

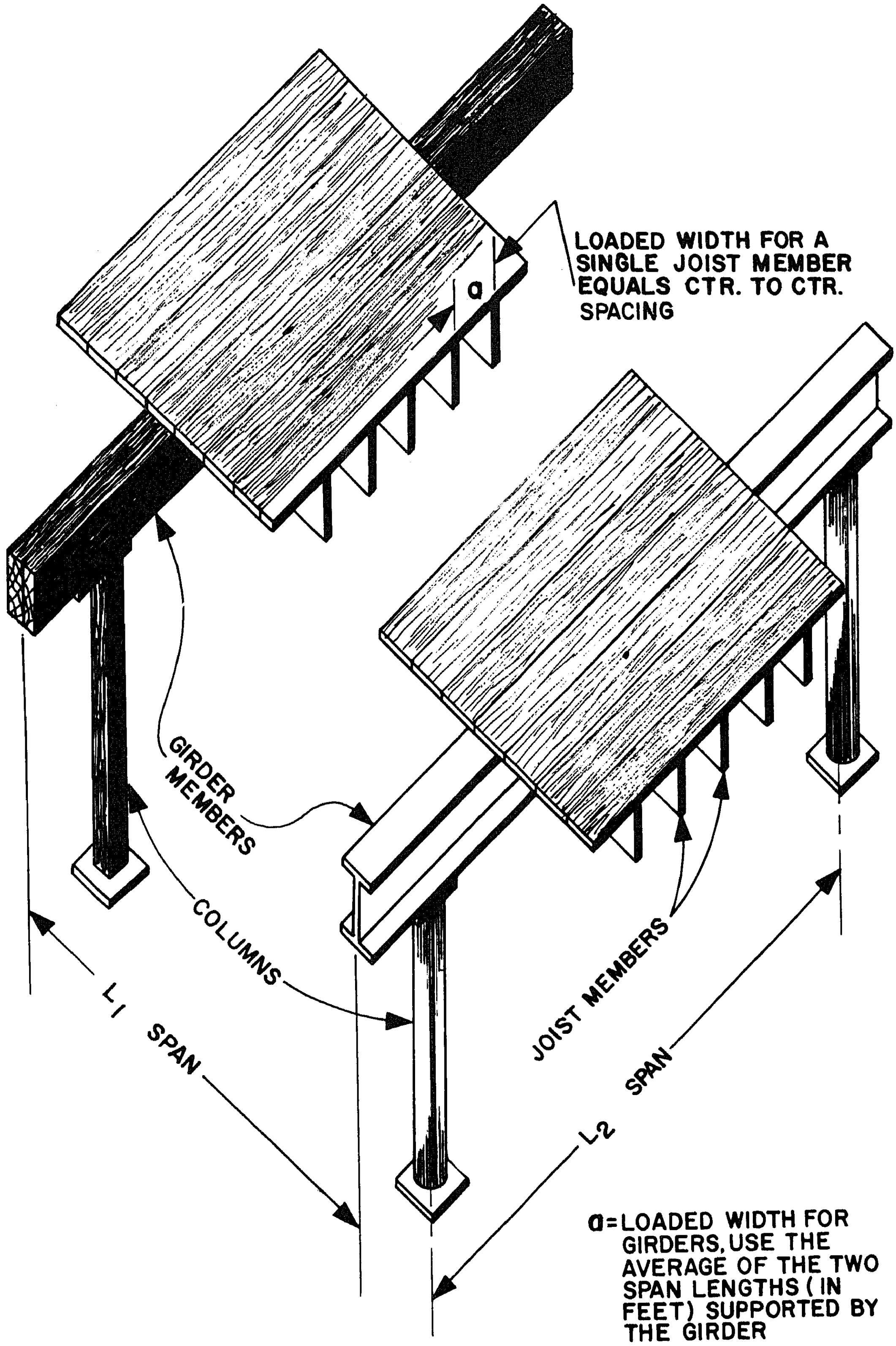
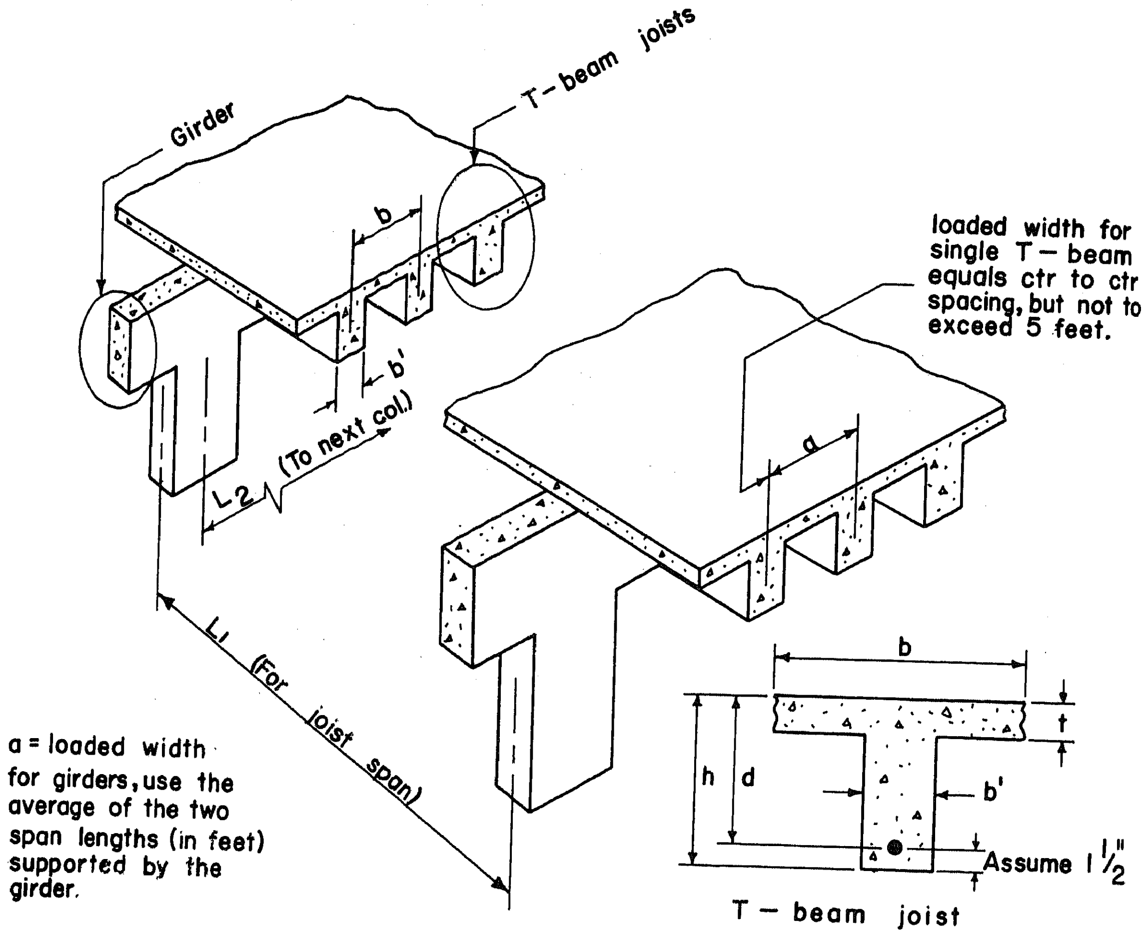


Figure 47. Typical basement roof framing system—steel and timber.



L_1 = MAX. SPAN LGTH FOR JOISTS.

L_2 = MAX. SPAN LGTH FOR GIRDERS.

Figure 48. Typical basement roof framing system—concrete.

because of collapse of the existing building above the basement.

(4) The capability of the basement walls to resist the air-induced soil pressures is not included in this procedure.

(5) All members are assumed to be adequately braced to resist lateral buckling. Bearing failures are not considered in this procedure.

(6) The stresses used in the derivations are assumed to be fixed for each particular material, regardless of the possible variations in the quality of the material. *For example,* all concrete is assumed to be 3,000 psi (211 kg/sq cm).

(7) This procedure is based upon the collapse or ultimate strength of the members; therefore, no consideration has been given to allowable deflections or damage permissible with each member. Based upon conventional ultimate strength design procedures

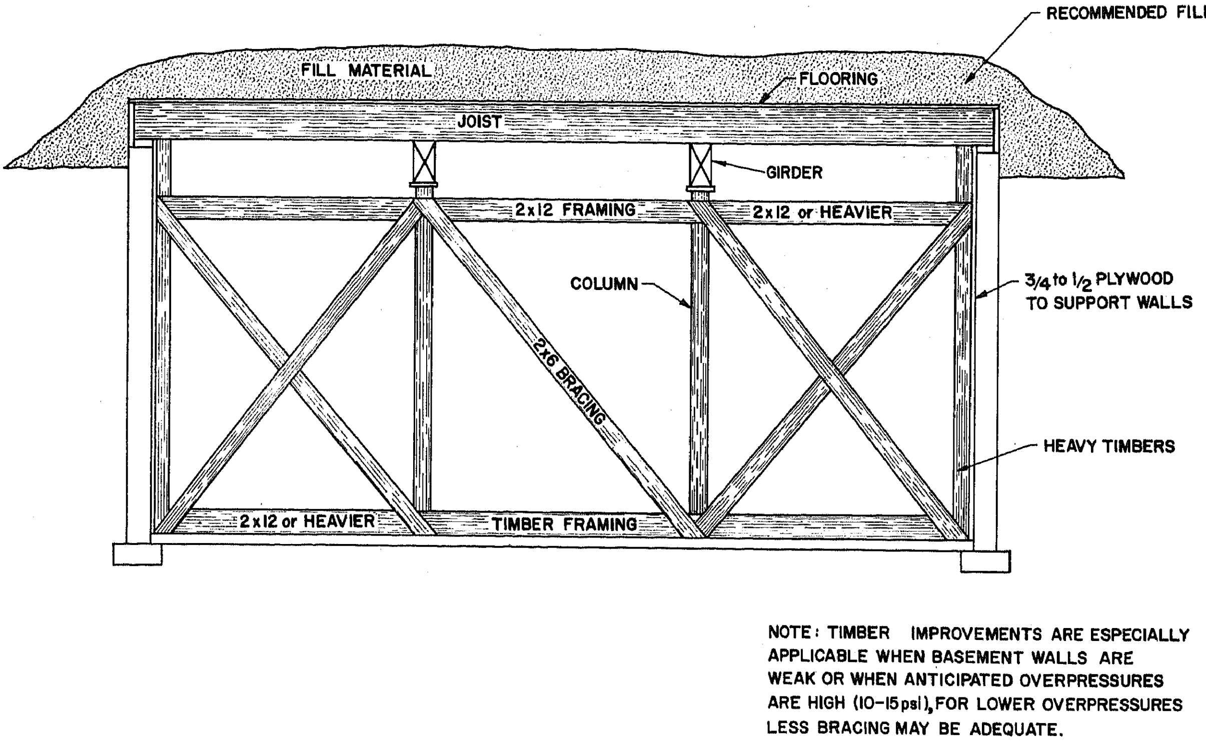


Figure 49. Recommended basement improvements.

using the assumed values for allowable stresses, a safety factor of 1 has been used.

(8) The allowable column loading (or minimum cross-sectional column areas) is based on a simply supported column 10 feet (3 meters) in length.

(9) Dynamic values were used in the derivations to account for the increased strain rate resulting from blast-type loading.

(10) The additional strength added to the floor joists due to substantial flooring is not included in the nomogram for floor joists. This is a conservatism.

(11) It is assumed that existing concrete columns are sufficient to carry the range of P_{so} from 1 to 15 psi (0.7 to 1 kg/sq cm).

64. Shelter Improvement

For the improvement of these shelters, the following details are recommended:

a. Add fill material of earth or rubble as shown in figure 49. A covering of 1 foot or more will provide some degree of radiation shielding, pressure sealing, and protection from thermal radiation, and burning of basement roof materials. Add the weight of the cover, estimated in psi, to the anticipated overpressure.

b. Seal all windows or openings in the basement walls as shown in figure 50.

c. Eliminate all frangible materials within the shelter to safeguard against injury from fragment missiles caused by the pressure pulse. This includes removal of masonry tile facings, plastered walls, or ceilings, all glass, hung ceilings, or any items suspended within the shelter which are potential missiles.

d. Protect all relatively fragile equipment, such as electronic gear or medical supplies, from any falling debris or fragments of concrete.

e. Remove all heavy machinery or equipment

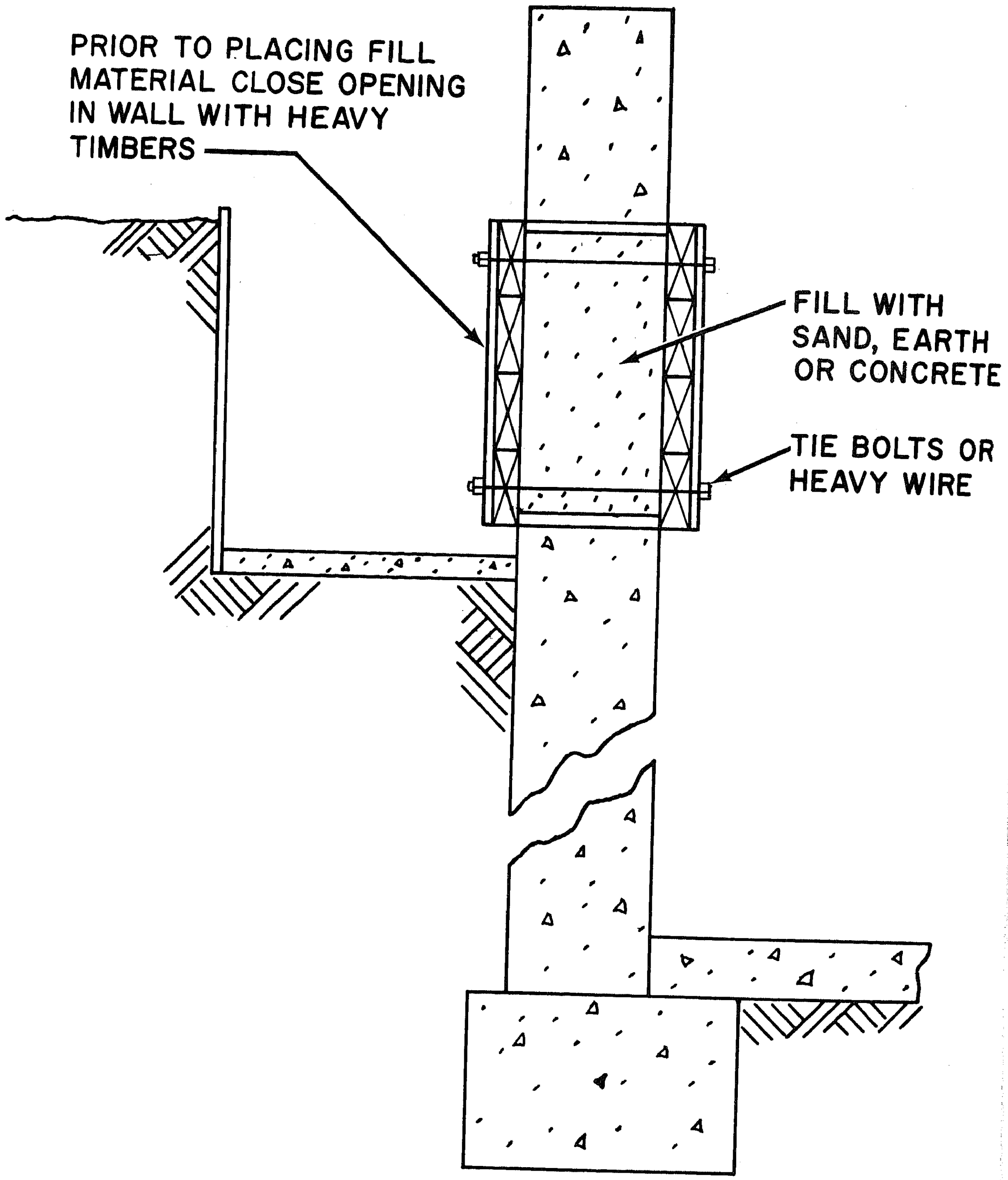


Figure 50. Recommended closure for openings in basement walls.

from the basement roof, or account for such items in the analysis.

f. For overpressures greater than 5 psi (35.15 gm/sq cm) or for saturated soil conditions, the neglect of the capacity of the basement walls to resist the air-induced soil pressures may be a hazardous omission. This is especially true if the walls are of concrete block.

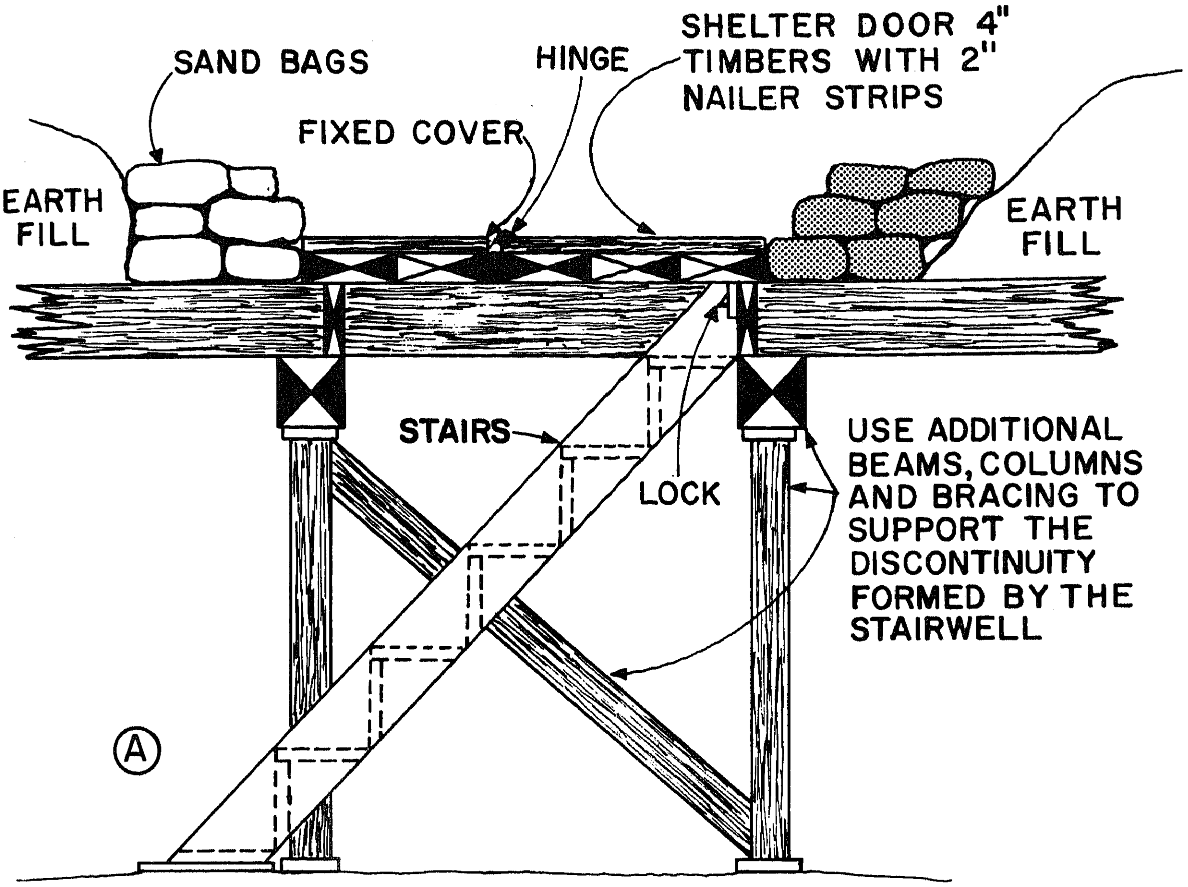


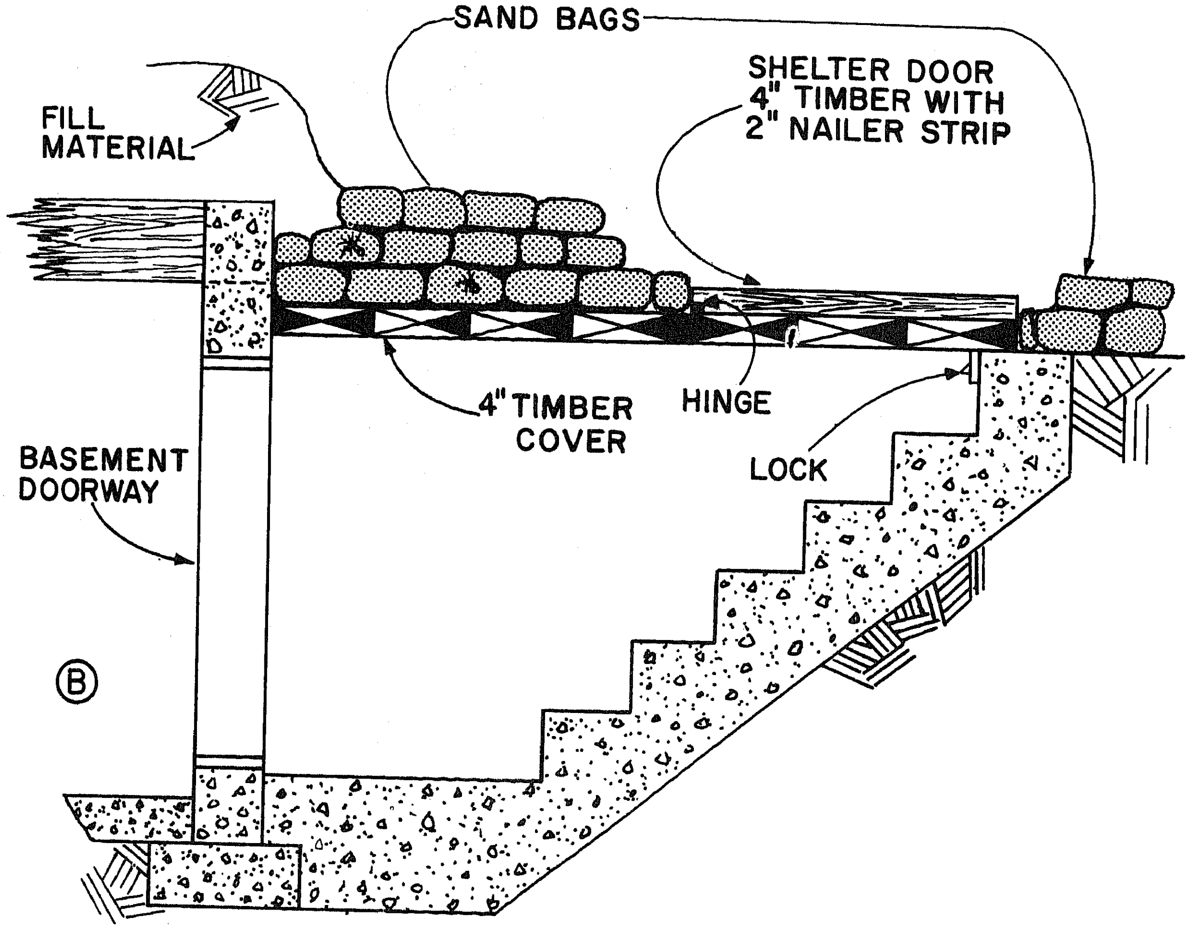
Figure [illegible]1. Entranceways improvements. (part 1 of 4).

Framing, as shown in figure 49, can be included to add support to the basement walls and provide continuity and strength to the entire structural system. With a cohesive and unsaturated soil and a concrete or heavy masonry wall, shoring the basement walls may be neglected.

g. Continuity and fixity of all joints, connections, and structural improvements are especially important in improving a blast-resistant shelter. It is recommended that all connections be bolted and reinforced with plywood gussets or timber splices. Avoid simply supported members. Lateral bracing of beams and columns should be included in the improvement plans. Tie the columns together with X bracing and horizontal members, as shown in figure 49, to gain additional strength and continuity of the improvement scheme. Plywood sheets ½-inch thick, well nailed to the existing flooring that form the basement roof, will significantly improve the strength of the joist members. The use of bolts, lag screws, or welding will increase the fixity of connections. Avoid the use of spikes or nails in the connections of main members.

h. Natural gas pipes, electrical wiring, and water pipes are vulnerable to blast damage. These prevent fire hazards or possible flooding of a basement shelter. Therefore, it is desirable to remove, or close off at some distance from the shelter, these potential hazards.

i. The existing structure above the basement roof is a potential hazard to the structure of the basement shelter. As the blast wave strikes



NOTE: With this situation it may be more desirable to close off the basement door shown in figure 51 (A) and backfill the stairwell. In this case an entrance through the floor could be constructed.

Figure 51. Entranceways improvements (part 2 of 4).

the stories above, horizontal and uplift forces are transmitted to the foundation walls. The collapse of partition-type walls, structural framing, and falling floors imposes impact loading on the basement roof. To account for these forces and impact loads, it is most desirable to remove the upper stories. Where this is not feasible, remove as much of the solid wall area as possible, leaving only the main framing. Sever all connections between the remaining structure and the foundation walls to eliminate or reduce the horizontal and uplift forces being transmitted to the foundation. To account for impact loadings, increase the anticipated overpressure by 100 percent of the estimated weight of the first story (or that portion not removed), 80 percent of the weight of the second story, and so on, reducing by 20 percent for each additional story. Use a minimum of 3½ psi (0.25 kg/sq cm) if none of the upper structure is removed.

j. Use base and cap plates when adding columns to improve the shelter. Paragraph 66 gives recommended sizes.

k. For wood columns longer than 10 feet, in-

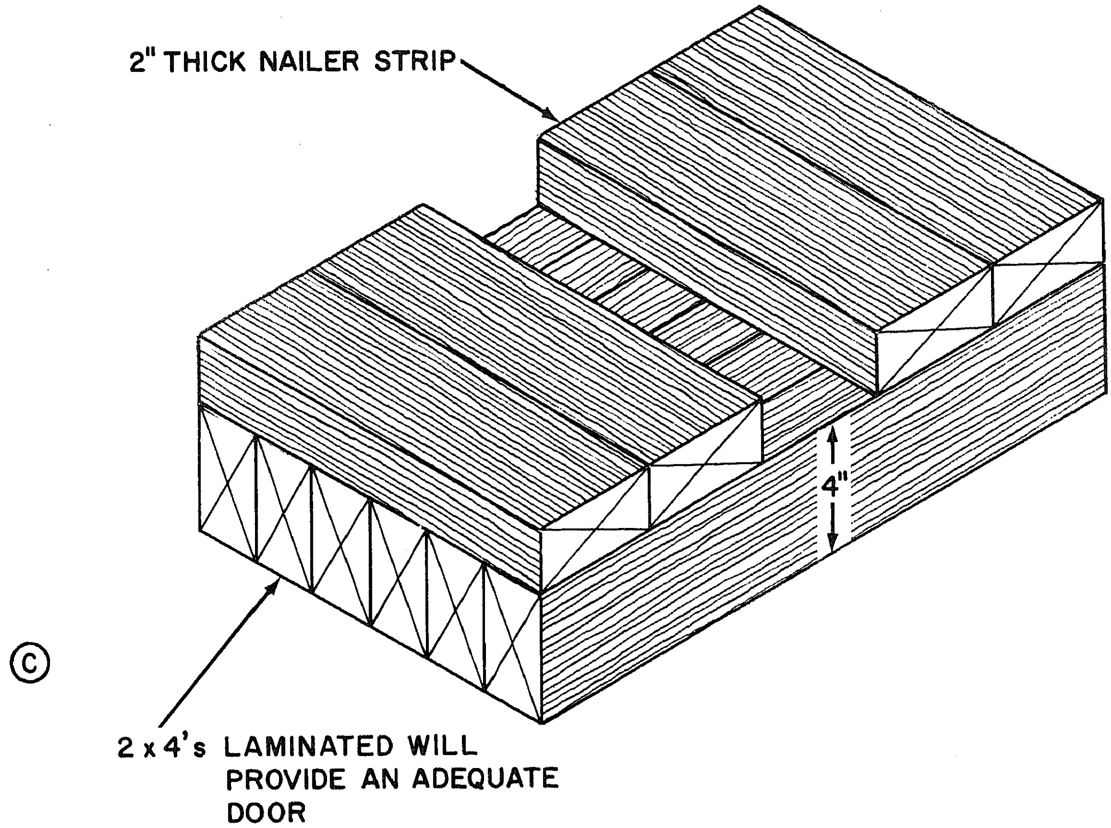


Figure 51. Entranceways improvements (part 3 of 4).

crease the minimum required area, A_w, by multiplying the nomogram reading by $H_c/120$, where H_c is the length of the column in inches.

l. Use as minimum column sizes the following: timber—4″ x 4″; steel—nominal 3″ pipe, 3″ I-beam, or wide flange section. Avoid using members that are weak in one direction, such as channels or angles. Two angles or channels can be welded together to form a box-shaped column sufficient to use.

m. Remove from the area above and surrounding the basement shelter all materials which are combustible, such as curtains, furniture, paper and trash, dry leaves, and the like, to protect the shelter occupants from the effects of carbon monoxide or suffocation and smoke inhaltion.

n. Provide an entrance to the shelter which is not vulnerable to an anticipated overpressure or fire. Recommendations for entranceways, are included separately in paragraph 65 and in figure 51 (parts 1 through 4).

o. The engineer should be aware of the other shelter requirements, such as radiation shielding and environmental considerations (given in ch. 2) for a complete protective shelter.

p. If improvements on the existing shelter roof are not feasible, the entire roof may be removed and replaced. The design of a stronger roof system can be made using the nomograms in figures 55 through 61.

q. All existing chimneys or vents leading to the basement through a furnace or heating unit should be sealed with concrete or removed.

65. Recommendations for Entranceway Improvements for Basement Shelters

The shelter should be improved so as to ex-

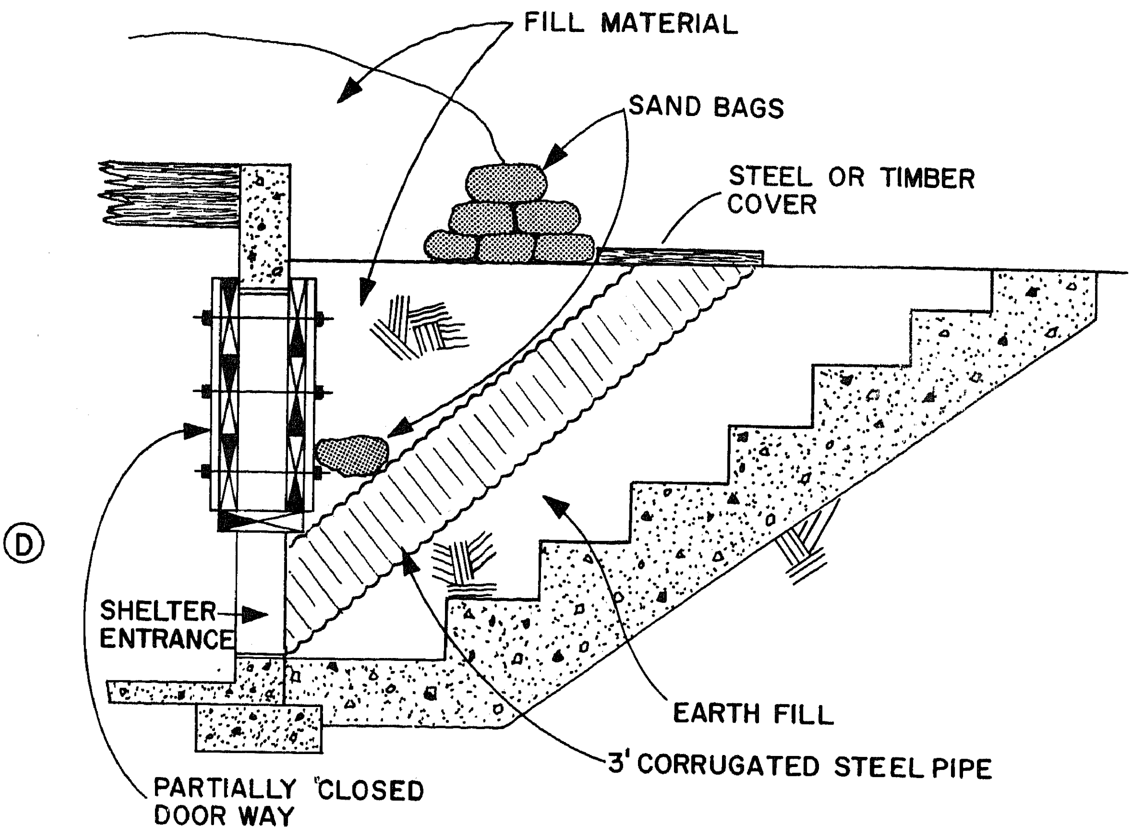


Figure 51. Entranceways improvements (part 4 of 4).

clude the sudden buildup of pressure within it. This can cause injury to personnel, including possible rupture of eardrums. The entranceway to a basement shelter is normally the most vulnerable element for pressure intrusion and the most difficult element to design. A horizontal door eliminates the buildup of reflected pressures and is probably the most reasonable for a basement shelter. The strength required of a horizontal door often results in having a door so heavy that the shelter occupants cannot easily remove the door to leave the shelter. Although special situations may require the imagination and ingenuity of the engineer, figure 51 (Parts 1–4) shows some entranceway improvements for common basement situations. In addition to the strength requirements of the entrance door, provisions should be made to waterproof the entranceway area. In some cases it may be more advantageous to close off a stairwell as shown in Part 1 of figure 51 and to cut a hole in the shelter roof elsewhere, using a ladder to enter the basement. The same doorway as given in Part 3 of figure 51 can be used, and the opening should be structurally reinforced. Provisions for an emergency exit should be considered due to possible obstruction of the normal entrance-exit. The scheme shown in figure 51 (Parts 1, 2, and 4) will not provide good protection from fallout radiation effects. To remedy this "weak link" for radiation hazard, the shelter door should be as small as possible and the horizontal area surrounding the door should be earth filled or covered with sandbags. Doubling or tripling the thickness of the door will increase the fallout protection somewhat. Another means for gaining radiation shielding would be to surround the stairwell beneath the floor with a wall of sandbags, thus forming a shaft from the basement floor to ceiling.

66. Recommended Column Cap and Base Plate Designs for Basement Shelter Improvement

a. Design of Column Base Plates (based upon the assumption that a concrete floor exists).

(1) Use a square, steel plate $2d$ on each side, where d is the largest cross-sectional dimension of the column.

(2) The plate thickness is given by $t = 0.09d$, where d is defined as above. Minimum: $t = \frac{1}{4}''$.

b. Design of Column Cap Plate.

(1) For timber girders, use a steel cap plate of width b equal to the width of the girder being supported and a length l given by: $l = \dfrac{0.144\,P_{so}\,A_L}{b}$, but not to be less than b. Use $t = 0.09l$ for thickness; A_L = loaded area ($L_1 \times L_2$); For L_1 and L_2, see figure 47; P_{so} = overpressure.

(2) For concrete girders, make the cap plate and base plate the same size. If the width of the girder is less than $2d$, use a cap plate as wide as the girder with a total area equal to the area of the base plate. Thickness given by $t = 0.09d > \frac{1}{4}''$.

(3) For steel girders and steel columns use a cap plate which completely covers the cross section of the column. A steel plate $\frac{1}{2}''$ thick will be adequate for all columns whose largest dimension is 6″ or less. For larger columns use $\frac{3}{4}''$ steel plate.

(4) For steel girders and timber columns, a cap plate is not required unless the smallest dimension of the column is less than the flange width of the girder. In this case, use a cap plate which covers the top of the column and a thickness as given by (3) above.

c. Recommendations for Cap and Base Plates.

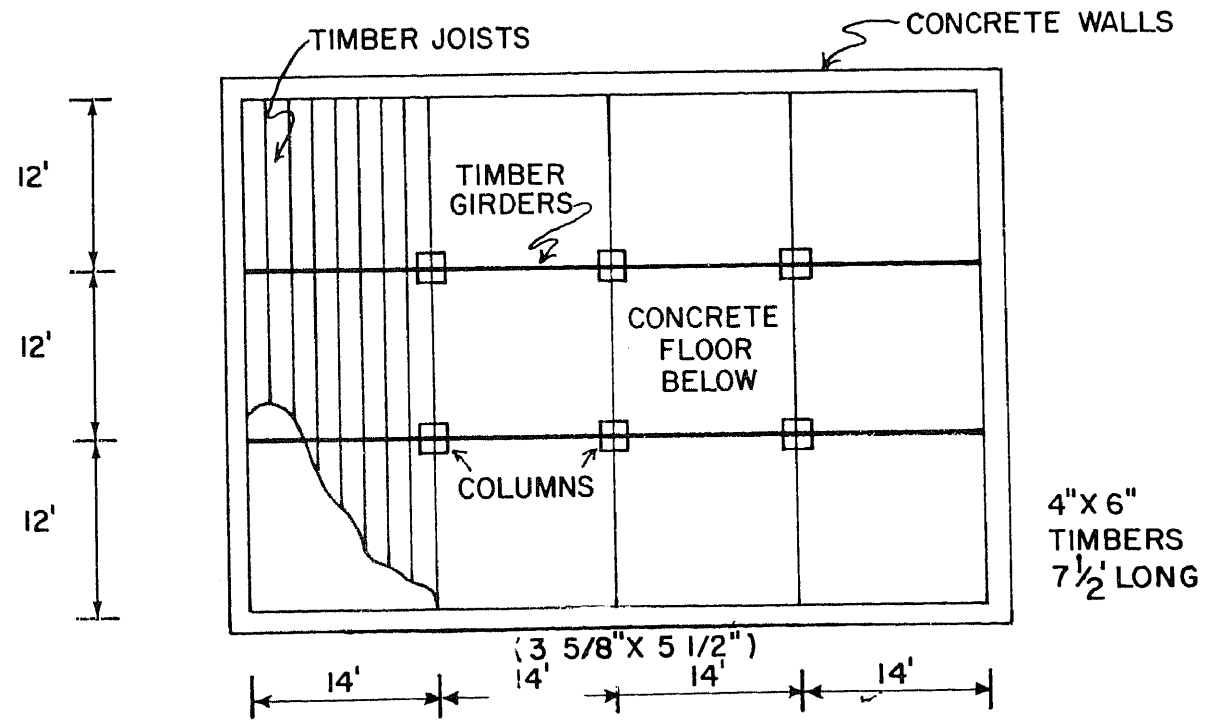


Figure 52. Plan of existing basement.

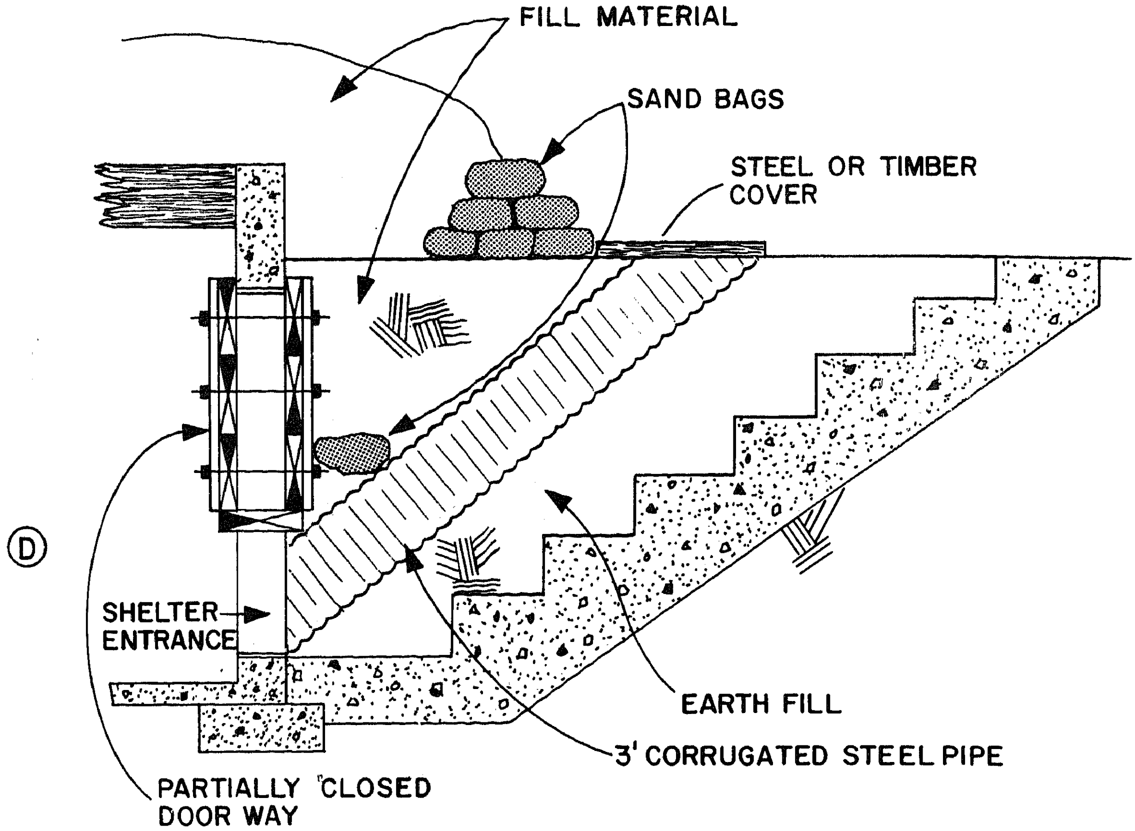


Figure 51. Entranceways improvements (part 4 of 4).

clude the sudden buildup of pressure within it. This can cause injury to personnel, including possible rupture of eardrums. The entranceway to a basement shelter is normally the most vulnerable element for pressure intrusion and the most difficult element to design. A horizontal door eliminates the buildup of reflected pressures and is probably the most reasonable for a basement shelter. The strength required of a horizontal door often results in having a door so heavy that the shelter occupants cannot easily remove the door to leave the shelter. Although special situations may require the imagination and ingenuity of the engineer, figure 51 (Parts 1–4) shows some entranceway improvements for common basement situations. In addition to the strength requirements of the entrance door, provisions should be made to waterproof the entranceway area. In some cases it may be more advantageous to close off a stairwell as shown in Part 1 of figure 51 and to cut a hole in the shelter roof elsewhere, using a ladder to enter the basement. The same doorway as given in Part 3 of figure 51 can be used, and the opening should be structurally reinforced. Provisions for an emergency exit should be considered due to possible obstruction of the normal entrance-exit. The scheme shown in figure 51 (Parts 1, 2, and 4) will not provide good protection from fallout radiation effects. To remedy this "weak link" for radiation hazard, the shelter door should be as small as possible and the horizontal area surrounding the door should be earth filled or covered with sandbags. Doubling or tripling the thickness of the door will increase the fallout protection somewhat. Another means for gaining radiation shielding would be to surround the stairwell beneath the floor with a wall of sandbags, thus forming a shaft from the basement floor to ceiling.

66. Recommended Column Cap and Base Plate Designs for Basement Shelter Improvement

a. Design of Column Base Plates (based upon the assumption that a concrete floor exists).

(1) Use a square, steel plate $2d$ on each side, where d is the largest cross-sectional dimension of the column.

(2) The plate thickness is given by $t = 0.09d$, where d is defined as above. Minimum: $t = \frac{1}{4}''$.

b. Design of Column Cap Plate.

(1) For timber girders, use a steel cap plate of width b equal to the width of the girder being supported and a length l given by: $l = \dfrac{0.144\, P_{so}\, A_L}{b}$

but not to be less than b. Use $t = 0.09l$ for thickness; A_L = loaded area ($L_1 \times L_2$); For L_1 and L_2, see figure 47; P_{so} = overpressure.

(2) For concrete girders, make the cap plate and base plate the same size. If the width of the girder is less than $2d$, use a cap plate as wide as the girder with a total area equal to the area of the base plate. Thickness given by $t = 0.09d > \frac{1}{4}''$.

(3) For steel girders and steel columns use a cap plate which completely covers the cross section of the column. A steel plate $\frac{1}{2}''$ thick will be adequate for all columns whose largest dimension is 6″ or less. For larger columns use $\frac{3}{4}''$ steel plate.

(4) For steel girders and timber columns, a cap plate is not required unless the smallest dimension of the column is less than the flange width of the girder. In this case, use a cap plate which covers the top of the column and a thickness as given by (3) above.

c. Recommendations for Cap and Base Plates.

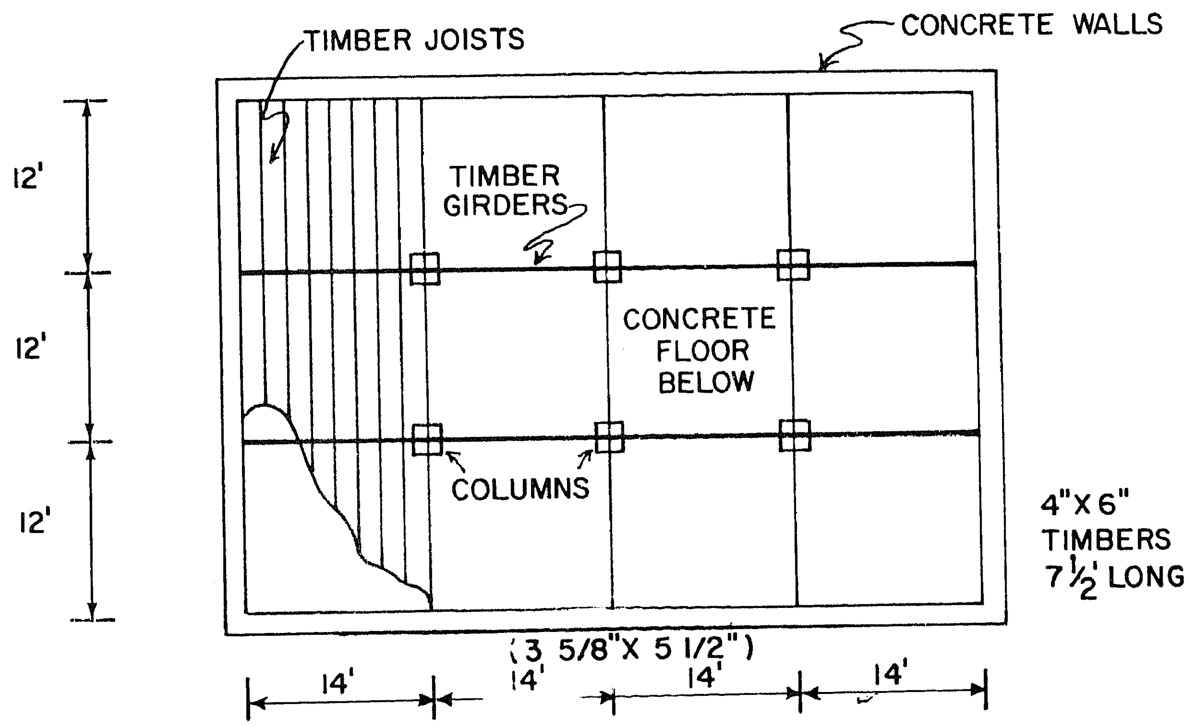


Figure 52. Plan of existing basement.

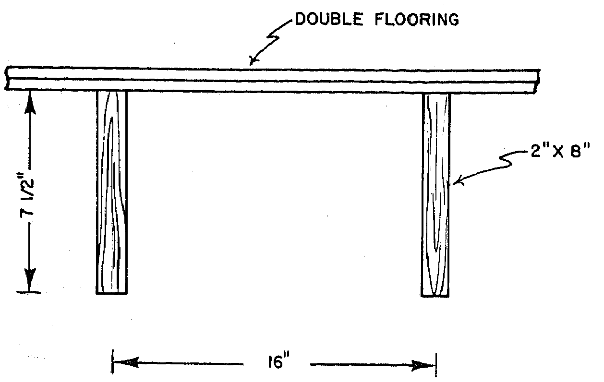


Figure 53. Section of joists.

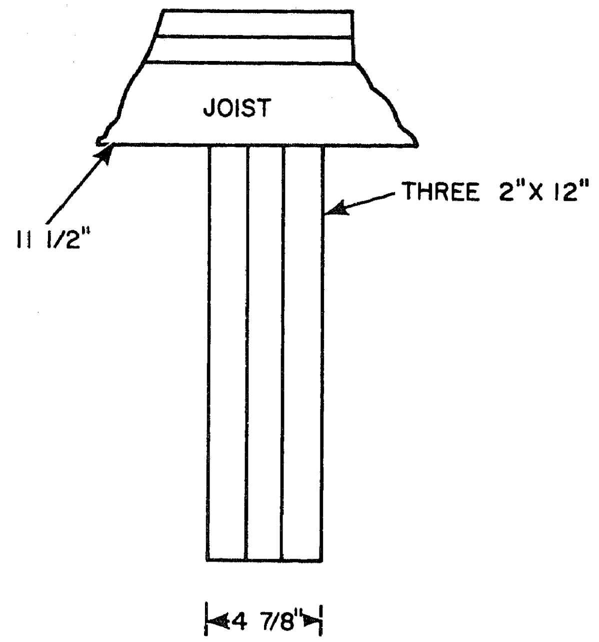


Figure 54. Section of girder.

(1) Fix the plates to the column, girder, and floor by welding, bolting, or screwing.

(2) If only timber plates are available, the sizes required are left to the judgment of the engineer. Even a wood base and cap plates are better than none at all if steel is not available.

(3) For basement floors other than concrete, the required base plate should be adjusted in accordance with the allowable bearing pressure of the existing floor. A timber grillwork may be required to distribute the column load. With a timber grillwork of heavy timbers, the base plate sizing recommended in *a* above may be used.

67. Analysis of Existing Basement for Allowable Overpressure

Given: See figure 52.

Joists: 2″ × 8″ set 16″ O.C.
(Dressed size = 1⅝″ × 7½″)
Girders: Three 2″ × 12″

Find: The allowable overpressure for the basement, based upon the weakest element.

Solution:

a. Analysis of joists (fig. 53).

(1) L_1 = 12 ft; a = 16″ = 1.33′ = loaded width (Given data) S = section modulus (2 × 8) = $\frac{bh^2}{6} = \frac{(1\frac{5}{8})(7\frac{1}{2})^2}{6}$ = 15.23 cu in
bh = area = (1⅝) (7½) = 12.19 sq in

(2) Check moment controlling criterion:
Figure 55 gives Pso (allowable) = 1.1 psi (77.3 gr/sq cm)

(3) Check shear controlling:
Figure 56 gives P_{so} (allowable) = 2.8 psi (196.8 gr/sq cm)

b. Analysis of Girders (fig. 54)

(1) L_2 = 14 ft; a = loaded width = 12 ft (Given data) S = section modulus = $\frac{bh^2}{6} = \frac{(4\frac{7}{8})(11\frac{1}{2})^2}{6}$ = 107.4 cu in
bh = area = (4⅞)(11½) = 56.1 sq in

(2) Check moment controlling:
Figure 55 gives P_{so} (allowable) = 0.6 psi

(3) Check shear controlling:
Figure 56 gives P_{so} (allowable) = 1.24 psi

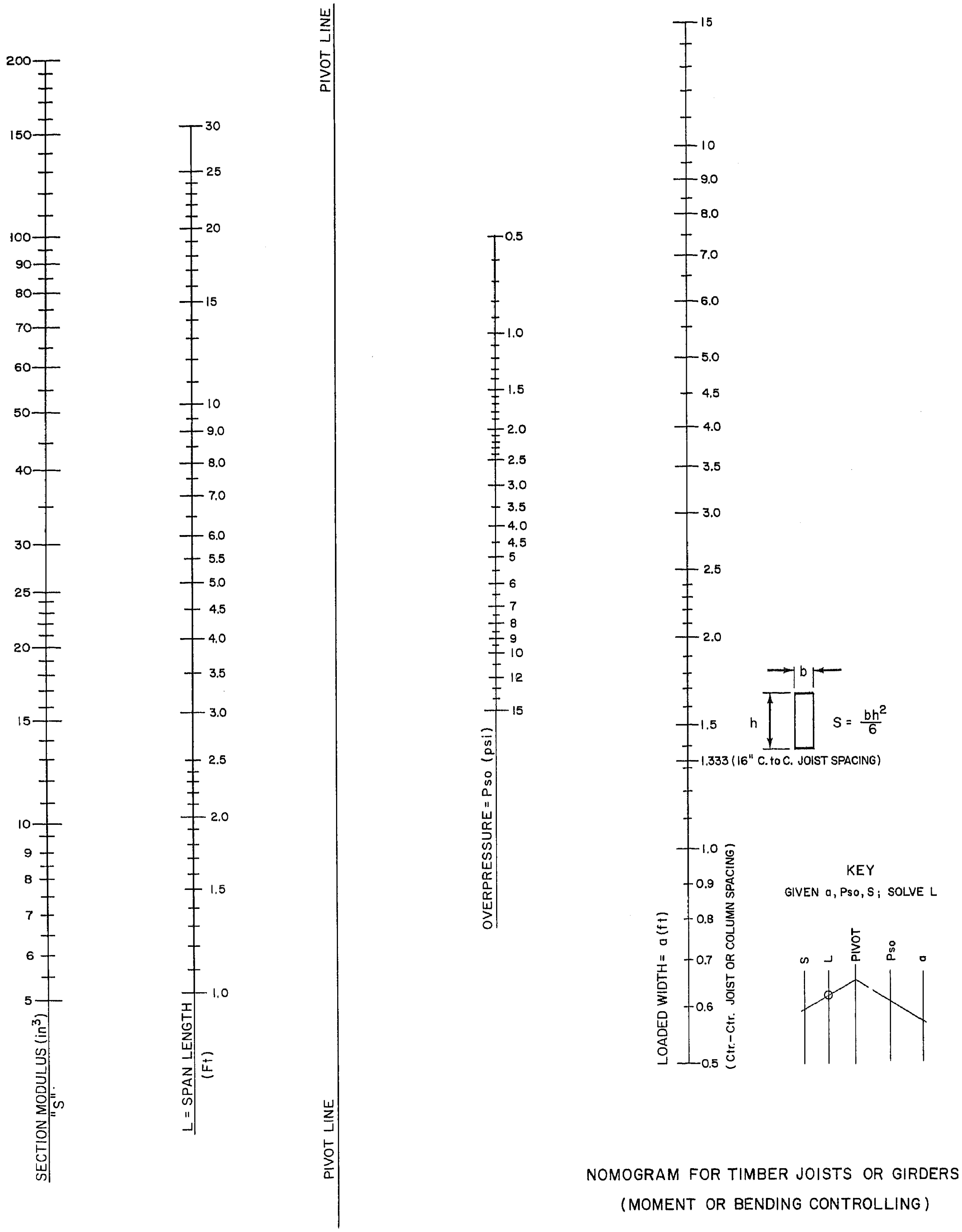


Figure 55. Nomogram—timber joists or girders (moment or bending controlling).

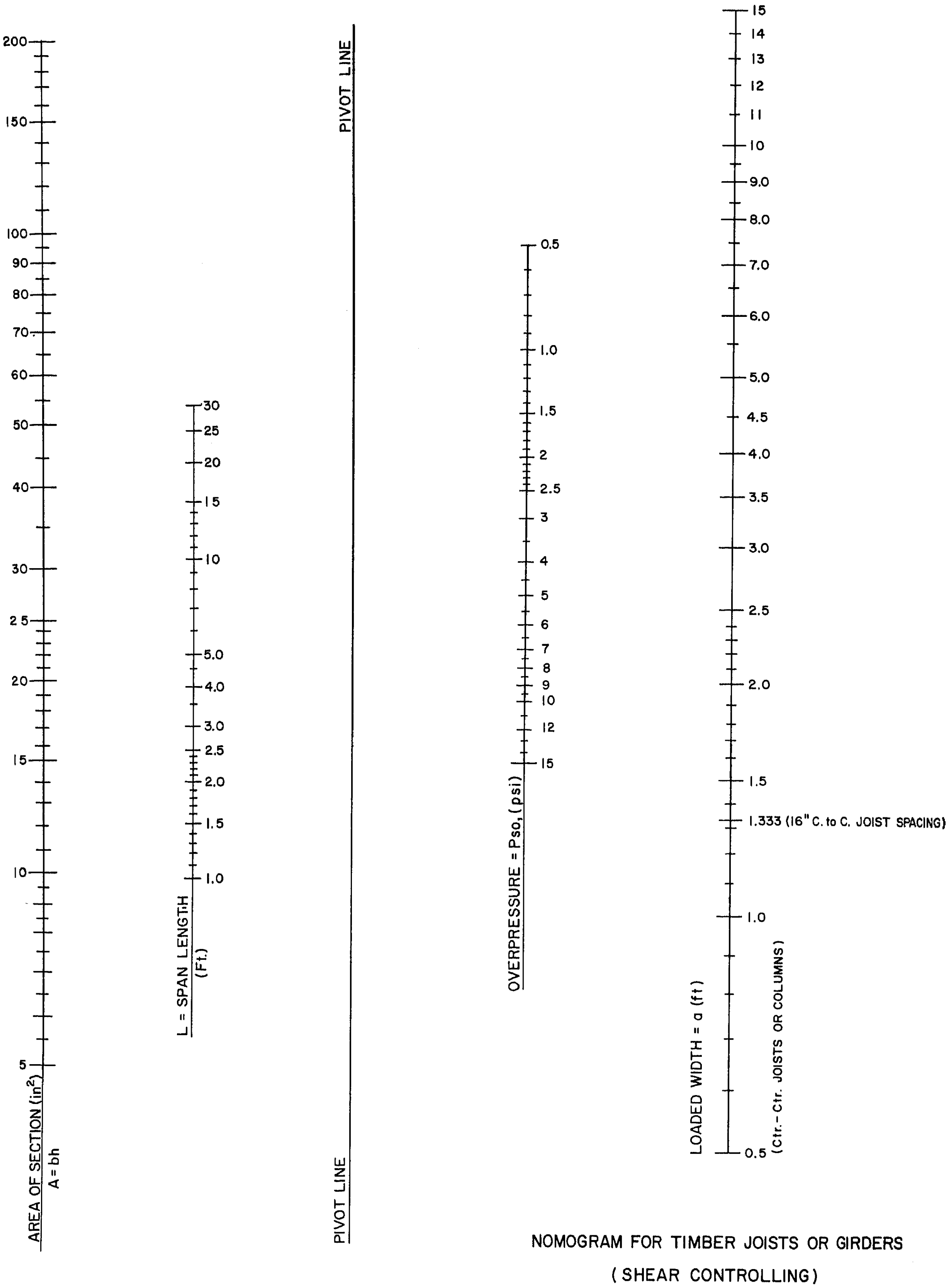


Figure 56. Nomogram—timber joists or girders (shear controlling).

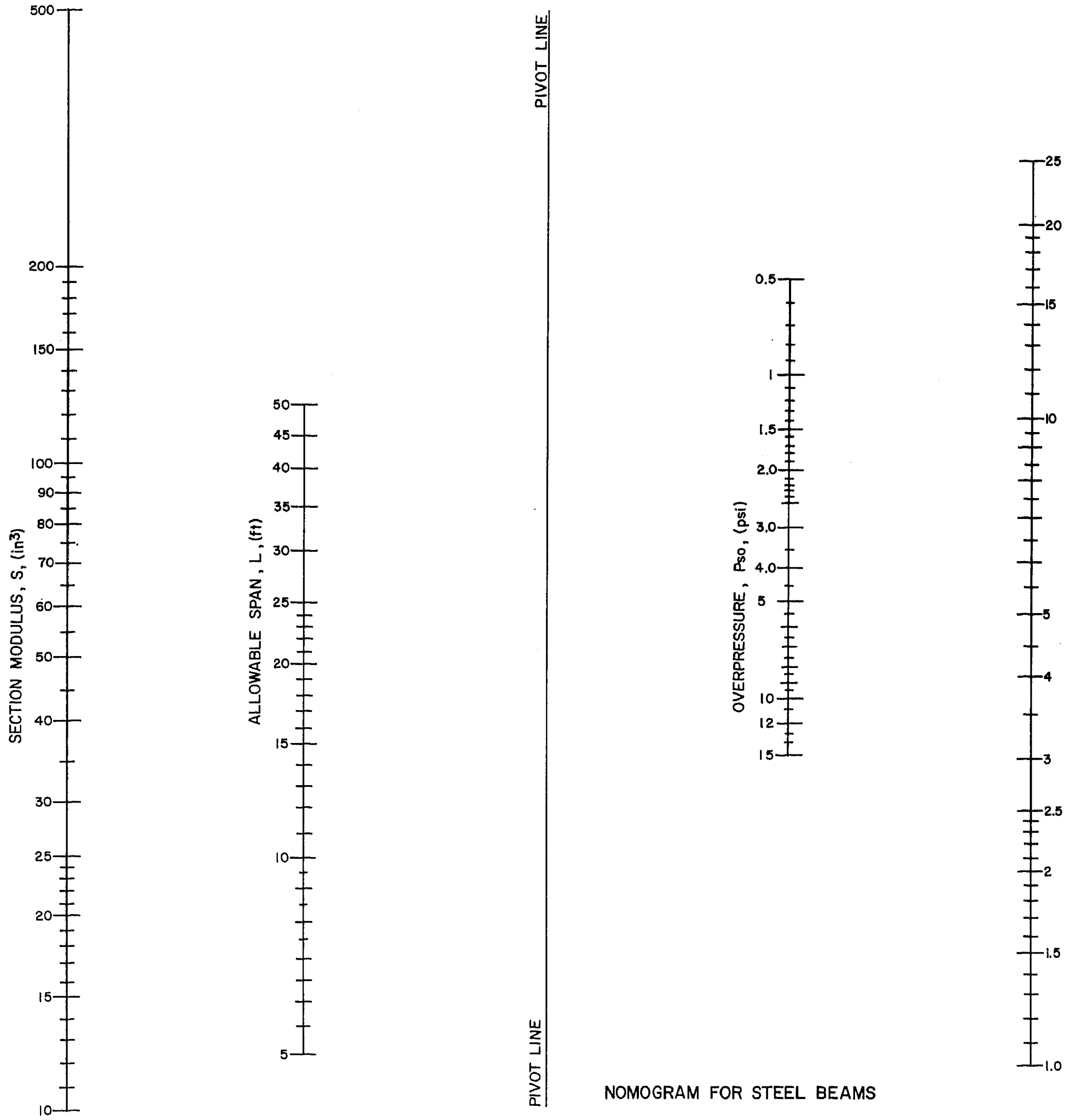


Figure 57. Nomogram—steel beams.

c. Analysis of Columns.

(1) A_L = loaded area = $L_1 \times L_2$ = 12′ × 14′ = 168 sq ft (Given data) A_w = area of 4″ × 6″ column = $(3\frac{5}{8})(5\frac{1}{2})$ = 19.94 sq in

(2) Figure 61 gives P_{so} (allowable) = 1.2 psi (83.4 gr/sq cm)

d. Conclusion. Based upon the failure of the girders in moment, the basement is valid for only 0.6 psi (42.2 gr/sq cm) as a shelter.

Note. The nomograms in figures 57 through 61 are included for problems wherein steel beams or reinforced concrete beams are involved.

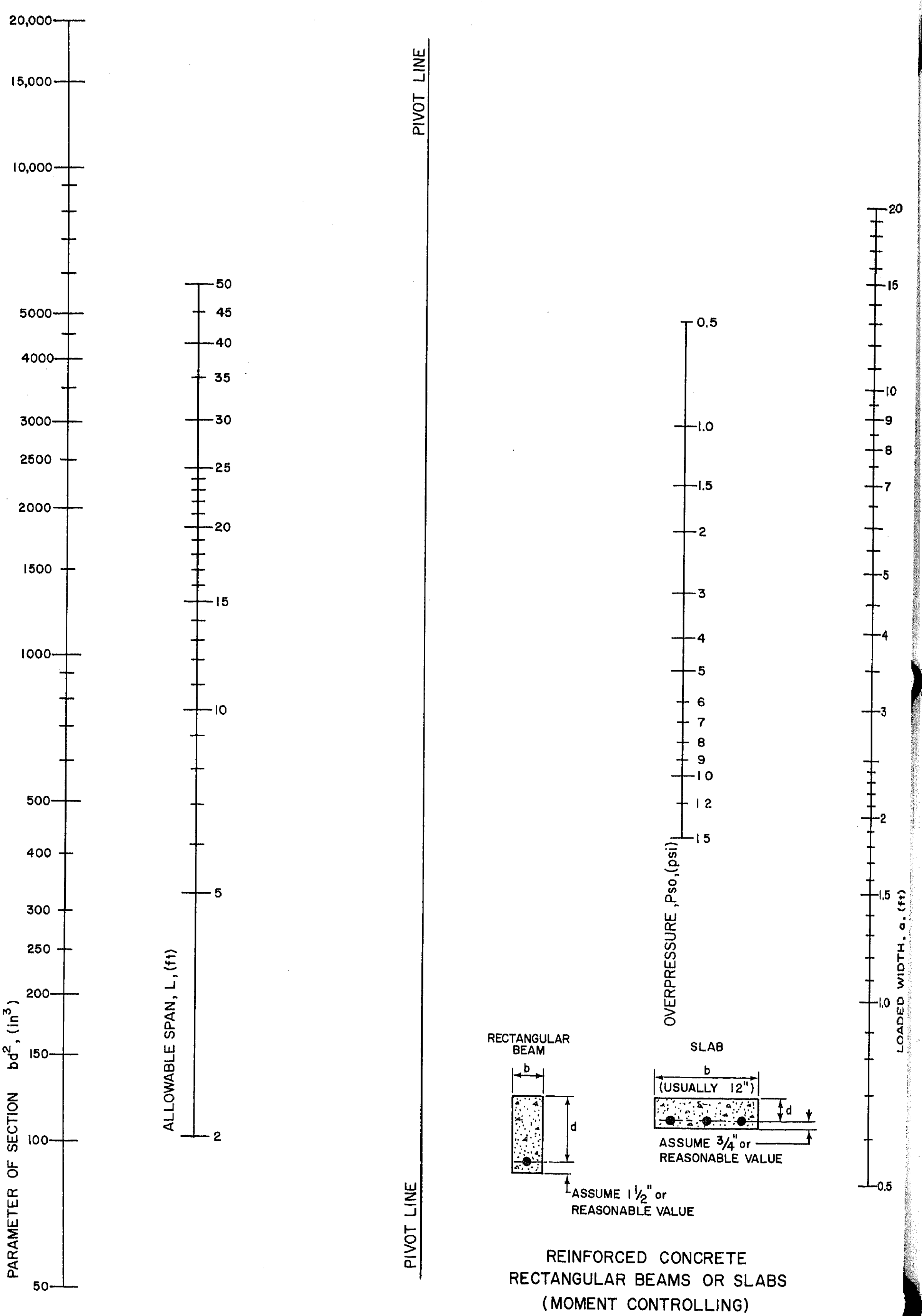


Figure 58. Nomogram reinforced concrete, rectangular beams or slabs (moment controlling).

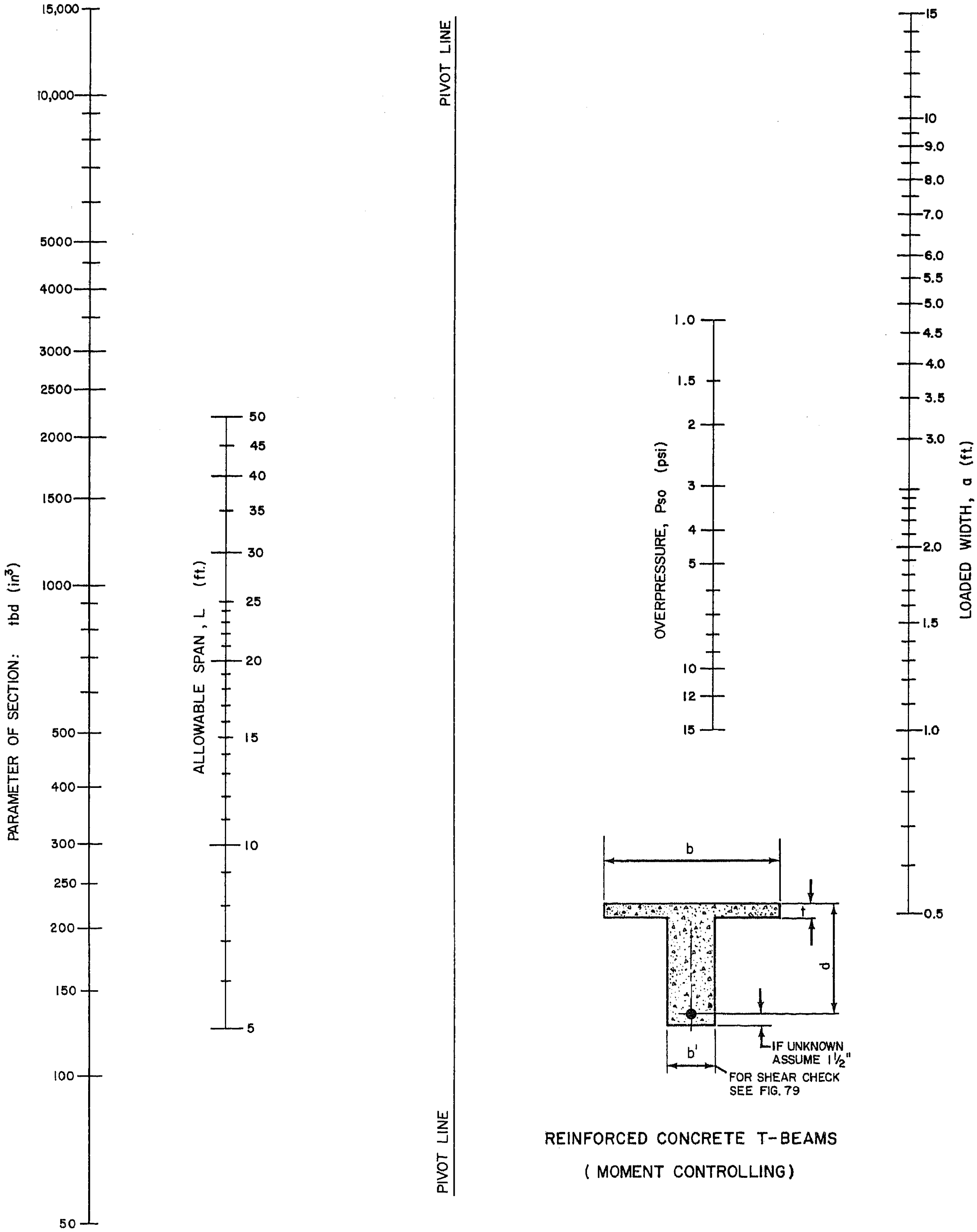


Figure 59. Nomogram—reinforced concrete T-*beams (moment controlling).*

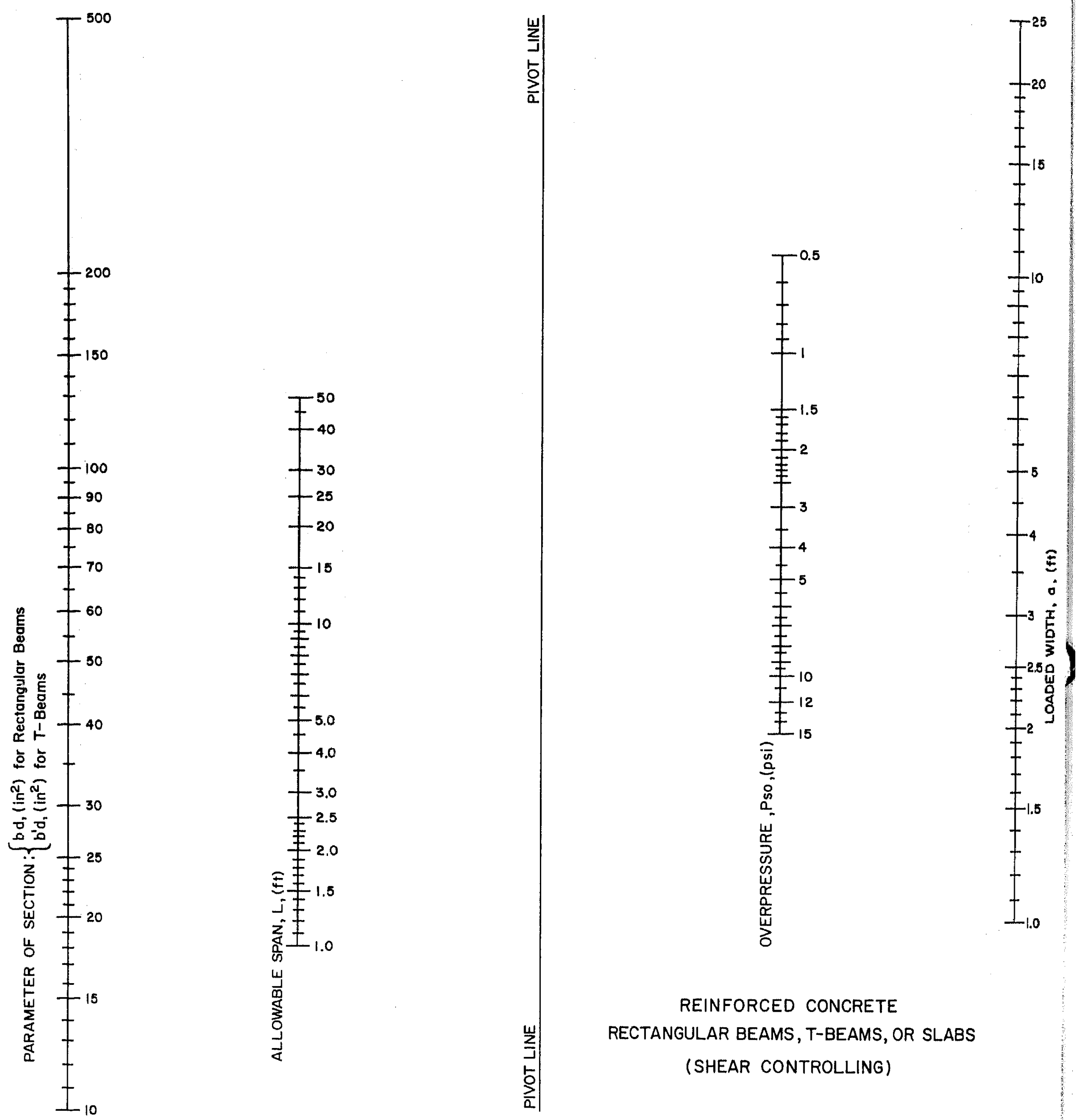


Figure 60. Nomogram—reinforced concrete, rectangular beams, T-*beams, or slabs (shear controlling).*

68. Shelter Improvement Example

Given: Same as in paragraph 67.

Find: Improvement necessary to make the basement of paragraph 67 withstand 5 psi (351.5 gr/sq cm) overpressure.

Solution:

a. Allowable Span for Existing Joists at 5 psi (351.5 gr/sq cm)

(1) Use data given in example in paragraph 67.

(2) Moment controlling:
Using $S = 15.23$ sq in, $a = 1.33$ ft; and $P_{so} = 5$ psi (351.5 gr/sq cm)

Figure 55 gives L_1 (max) $= 5.6$ ft.

(3) Shear controlling:
Using $bh = 12.19$ sq in, $a = 1.33$ ft; and $P_{so} = 5$ psi
Figure 56 gives L_1 (max) $= 6.8$ ft.

(4) Conclusion: A span length of 6 ft may be assumed adequate. To reduce the span of the joints to 6 ft by adding a girder, the width of the girder, the existing double floor, and the continuity of the joists over an improvement girder justify this conclusion.

b. Allowable Span for Girders at 5 psi (351.5 gr/sq cm).

(1) Assume that the improvement girders which limit the span of joints are to be three 2″ x 12″. This limits the loaded area for each girder to 6 ft.

(2) Moment controlling:
Using $S = 107.4$ cu in, $a = 6$ ft and $P_{so} = 5$ psi
Figure 55 gives L_2 (max) $= 7.05$ ft

(3) Shearing controlling:
Using $bh = 56.1$ sq in, $a = 6$ ft; and $P_{so} = 5$ psi
Figure 56 gives L_2 (max) $= 6.92$ ft

(4) Conclusion: By adding 3 more girders to limit the joists span and placing new columns every 6 feet along the girders, the required 5 psi can be attained.

c. Required Sizes for Additional Columns.

(1) Given: $A_L = L_1 \times L_2 = 6 \text{ ft} \times 7 \text{ ft} = 42$ sq ft
$P_{so} = 5$ psi

(2) Figure 61 gives A_w (required) $= 20.5$ sq in.

(3) Conclusion: The dressed size of a 4″ x 6″ timber column gives an area of 19.94 sq in. This is sufficiently close to the required area of 20.5 sq in for existing columns. Since figure 61 is based upon a column of 10 ft in length, the engineer is justified in using 4″ x 6″ columns at 7½ ft for the required improvements. Figure 61 may also be used to determine the required area of a steel column. Using $A_L = 42$ sq ft and $P_{so} = 5$ psi, figure 61 gives:

A_s (required) $= 1.0$ sq in.

Therefore, the minimum size column (3″ nominal pipe column) as stated in paragraph 64*l* will be sufficient.

d. Determination of the Required Base and Cap Plates for the Columns.

(1) Assume 4″ x 6″ timber columns and concrete floor.

(2) Use the recommendations given in paragraph 66.

(3) Base plate required:
$d = 5\tfrac{1}{2}''$ = largest dimension of the column $\therefore$ $2d = 11''$ = length of the side of a square, steel base plate $t = .09d = (.09)(5\tfrac{1}{2}) = 0.495$ in.
$\therefore$ Use ½-inch thick steel plate.
Base plate: 11″ x 11″ x ½″ steel plate

(4) Cap Plate required:
Width of steel plate $= b =$ width of girder $= 4\tfrac{7}{8}$ in
Length of steel plate is given by:

$$l = \frac{(.144)\, P_{so}\, A_L}{b} = \frac{(.144)(5)(42)}{4.875} =$$

l (minimum) $= 6.2$ in.
Thickness required $= t = .09l$
$t = (.09)(6.2) = 0.56$ in.
Use ⅝″ plate
Cap plate: 4⅞″ x 6¼″ x ⅝″

69. Summary of Shelter Improvements

a. Three girders composed of three 2″ x 12″ must be added.

b. Additional columns of 4″ x 6″ timber are required to support the additional girders and reduce the span of the existing girders.

c. Cap and base plates for the additional columns are required. Increasing the size of the existing cap and base plates may or may not be justified. If a steel base and cap plate of

any size exists, the additional effort required to replace these plates would be justified.

d. In addition to the above improvements, additional bracing, gussets, and timber splice plates can be included to add fixity to the connections and joints, and continuity to the beams.

e. The recommendations for an earth cover and entranceways should be included in an actual shelter improvement.

f. If an earth cover of 2 feet (0.6m) is assumed at 90 pounds per cu ft (1442 kg/cu m), uncompacted, the allowable overpressure must be reduced by the amount of the weight of fill. This reductions for 90 pounds per cu ft of soil would be:

90 lb cu ft × 2 ft × sq ft/144 sq in = 1.25 psi (88 gr/sq cm)

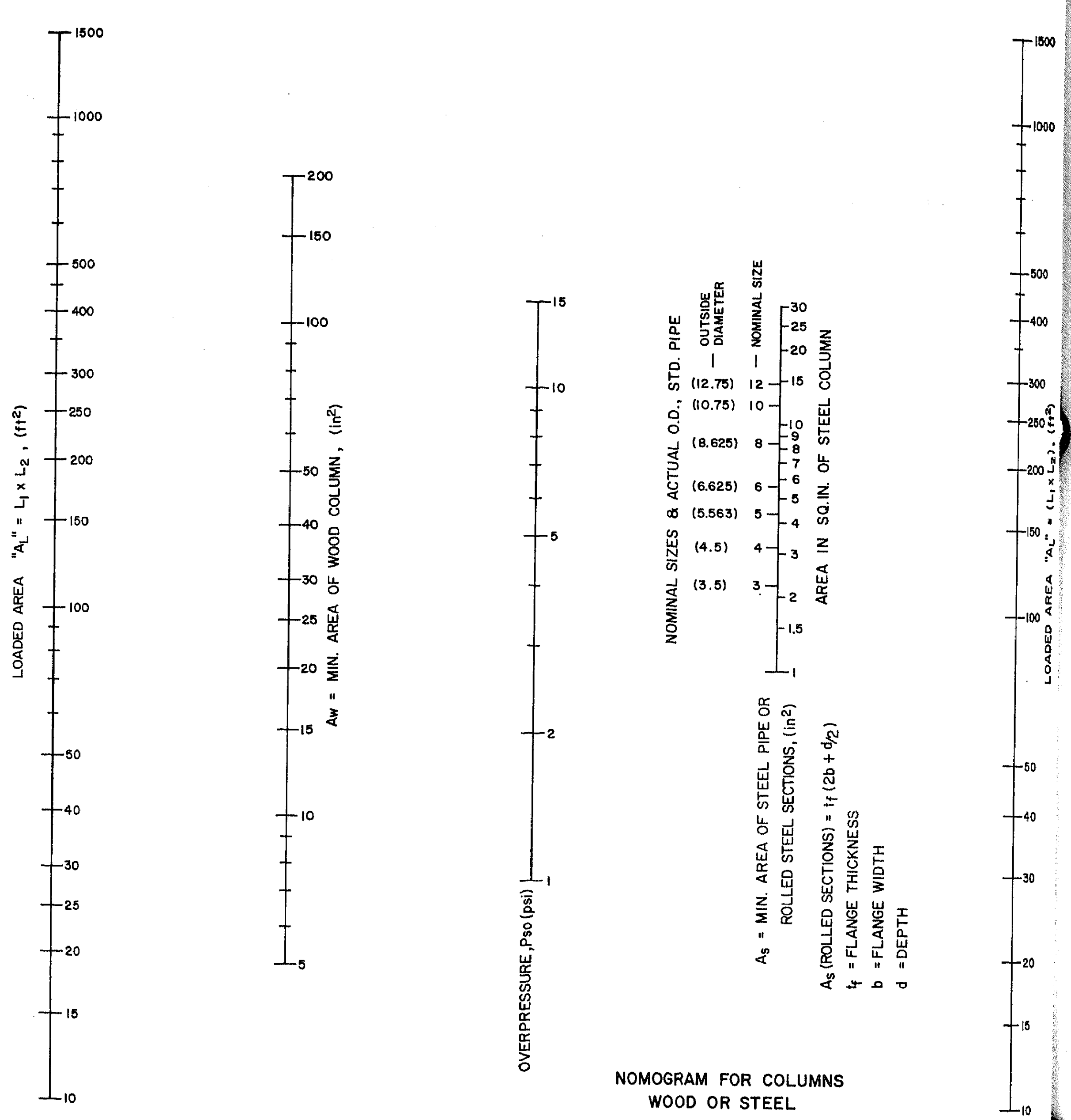


Figure 61. Nomogram—columns, wood or steel.

70. General Character of Fortifications

There are, in all parts of the world, existing fortifications of various styles, periods, purposes, and materials. These fortifications have been built along invasion routes, near harbor entrances and navigable rivers and canals, and surrounding major cities. These works vary greatly in their purpose, design, and state of preservation. Each facility must be examined by professionally qualified engineers who are skilled in analysis of structural design and strength of materials to determine its usefulness as a potential shelter against nuclear weapons. Many of these fortifications are structures of great strength; others are too antiquated or imperfect, both in design and materials of construction, to be considered. Many of the latter, however, contain subterranean passages between a main citadel and outer works and also contain magazines of great strength. Existing fortifications will first be analyzed by the materials used in their construction and then by their military function and the weapons system of the period in which they were built.

71. Adopting Specific Types of Fortifications as Shelters

a. Useful Fortifications.

(1) From earliest times stone and brick have been used as construction materials. The older fortifications (mostly those earlier than 1700) are generally not usable as shelters against nuclear weapons, except in certain cases where they have very solid towers. They should not be considered as shelters if there are more modern structures available. Even for fortifications built after 1700, the storage magazines and the bombproof areas for sheltering the garrison are the only useful areas to consider.

(2) Fortifications underwent change after the advent of rifled artillery (about 1870). There are seacoast fortifications, ring forts around cities, and the barrier forts on the frontiers. Generally they do not need structural analysis because their strength is far

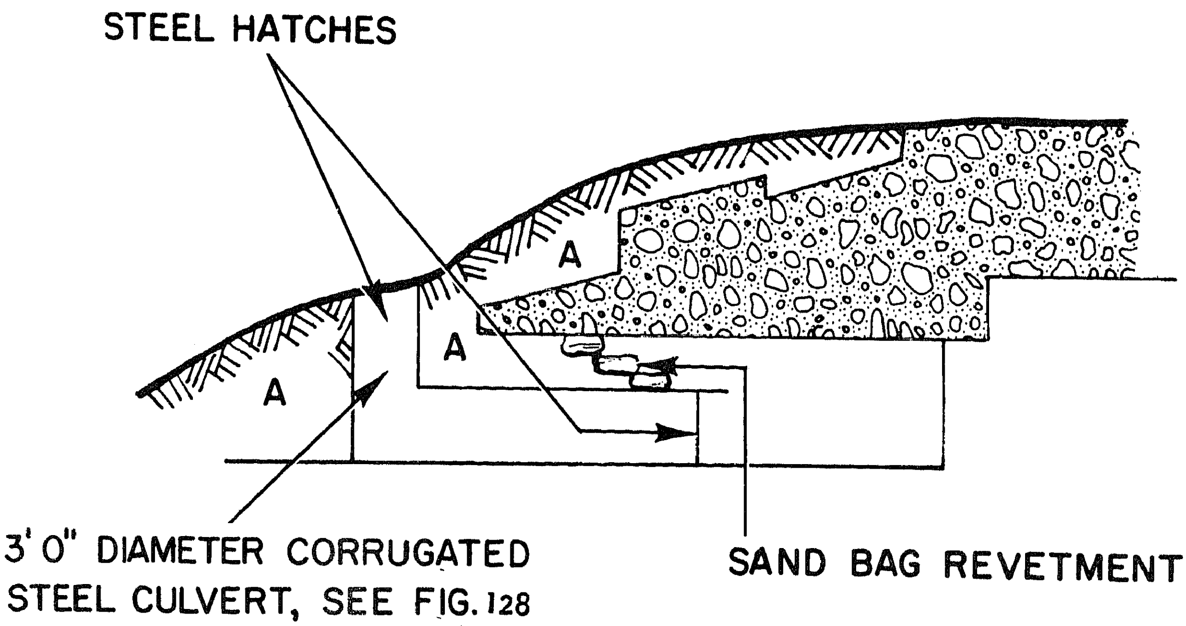


Figure 62. Circular or cattle-pass culvert.

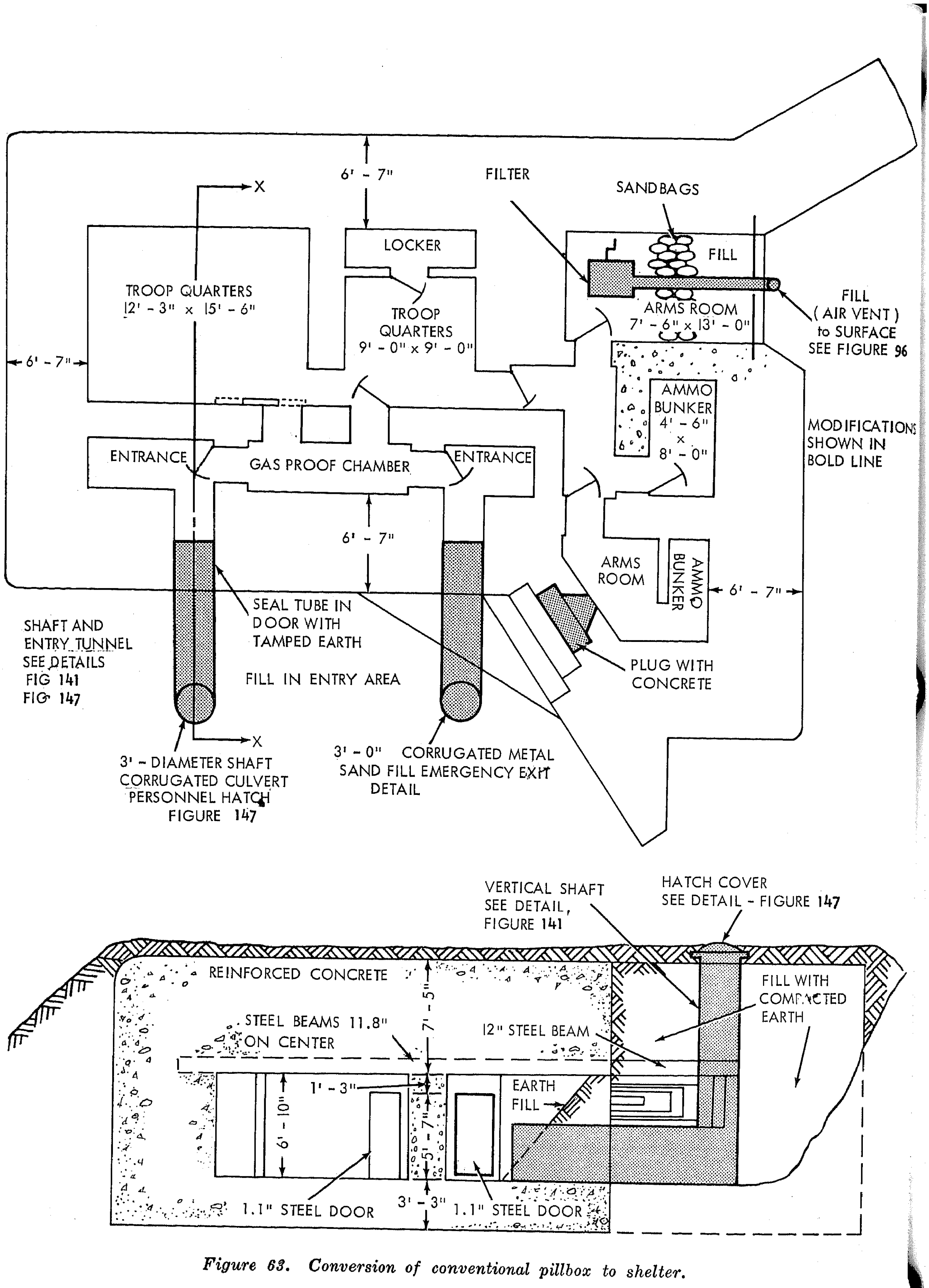


Figure 63. Conversion of conventional pillbox to shelter.

above that required, although their underground connecting tunnels may need such analysis.

b. *Modifications.*

(1) About the only modifications necessary in the reinforced concrete fortifications are in the entrance closures.

(2) In general, the parts of seacoast fortifications usable for shelters are the magazines and plotting rooms which have heavy overhead cover. Again, the conversions necessary are the entrances. Vertical and horizontal shafts are recommended for such conversions. Figure 62 shows this conversion.

c. *Conventional Pillbox Shelters.* This type of fortification exists in many parts of the world and is presented here as a type rather than as a specific set of fortifications (fig. 63). This solution to shelter requirements is the one to use with the modern independently sited pillbox wherever located. It should be noted that the solutions to entryways shown here are similar to those of the seacoast fortifications. These entryways can be reinforced by welding structural shapes across the shortest dimension of the door.

Section IV. MINES, TUNNELS, AND CAVES

72. Introduction

a. *Basic Study of Facility.* The use of mines, tunnels, and caves as shelters against nuclear weapons has many advantages from the standpoint of the large area of shelter produced for the amount of effort expended under favorable circumstances. The determination as to the feasibility, safety, and effort required is a matter of professional judgment in the field of engineering. During the reconnaissance and planning phase a study should be made by a mining engineer, or if none is available, a team consisting of a civil engineer and a geologist. This basic study of the proposed use of a facility should include a survey to determine the geological nature of the area, the net usable area of the facility, less space required for entrance doors, and blocking off of unsafe shafts, drifts, robbed-pillar areas, and so on. An investigation of an existing underground opening is not as thorough as that for a new tunnel or mine. When inspecting a structure there is neither time nor facilities for a complete geological investigation. Therefore, a judgment of the original constructors as to support, along with a general inspection of the opening, should show whether or not it is feasible to use the structure and, if it is feasible, what modifications are necessary.

b. *Criteria for Choosing Opening.* Any investigation of an underground opening will include a study of the surface and subsurface area, as well as intelligence obtained from the people who work in (or live near) a tunnel, mine, or cave. Such intelligence would probably be the more helpful. Criteria of shelter requirements must be set before an investigation can be made. When underground, rock defects rather than rock types govern the choice of a site.

73. Rock

a. *Type of Rock.* The resistance of rock to static and dynamic loading is dependent on its structural properties and the geologic structure of the rock mass. The former can be determined in a laboratory; the latter requires a field survey. The rocks likely to be encountered are igneous and sedimentary. Two common examples of igneous are granite and basalt. Dolomites belong to the sedimentary group. Rocks of the metamorphic type are not considered here because they will not be encountered.

b. *Rock Conditions.* When going underground, the desirability of rock is influenced by its condition. The following terms describe these conditions; they are listed in order of least support required. In practice, there are no sharp boundaries between these rock categories, and the properties indicated by each one of the following terms can vary between wide limits.

(1) *Intact.* This rock has neither joints nor hair cracks.

(2) *Moderately jointed.* The rock contains joints and hair cracks, but the blocks between the joints are locally grown together or intimately interlocked.

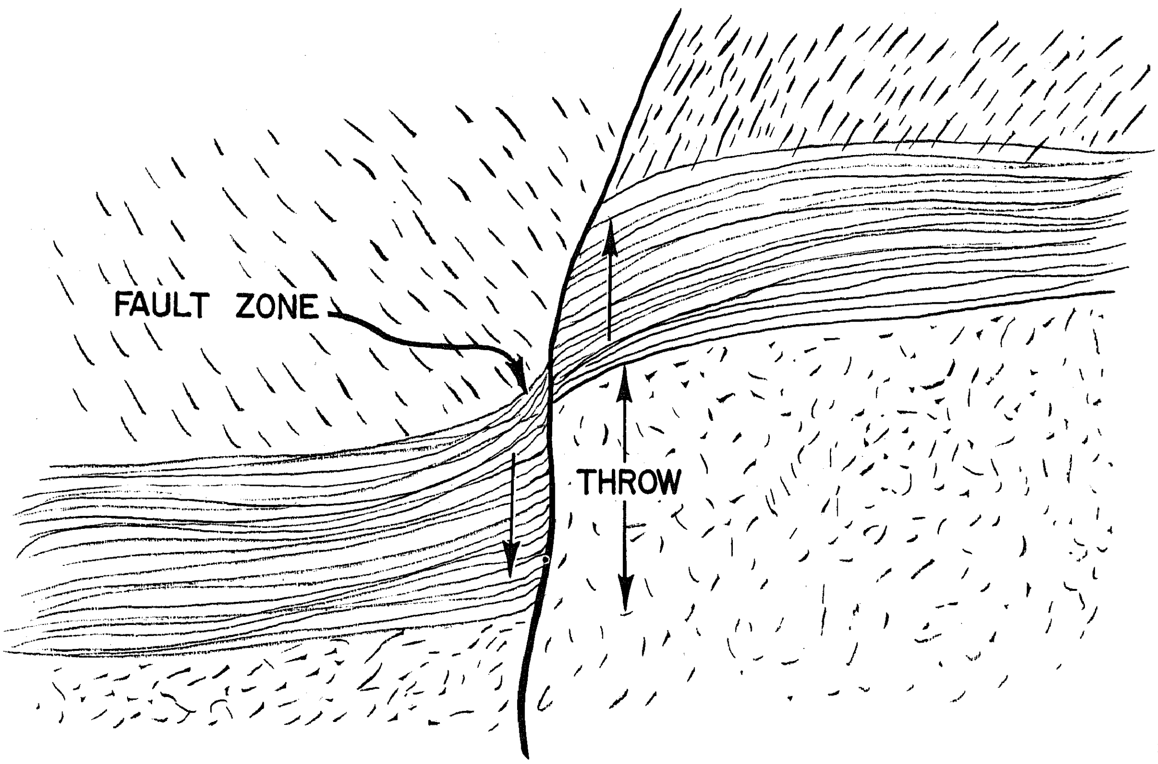


Figure 64. Normal fault.

(3) *Stratified.* This rock consists of individual strata with little or no resistance against separation along the boundaries between strata. The strata may or may not be weakened by transverse joints.

(4) *Blocky and seamy.* Rock in this condition consists of chemically intact, or almost intact, rock fragments which are entirely separated from each other and imperfectly interlocked.

(5) *Crushed.* This crushed, but chemically intact, rock has the characteristics of a crusher run. If most of the fragments are as small as fine sand grains, and no recementation has taken place, crushed rock below the water table exhibits the properties of water-bearing sand.

(6) *Squeezing.* This rock slowly advances into the underground opening. This advance is caused by a high percentage of microscopic particles of micaceous or clay minerals with a low swelling capacity.

(7) *Swelling.* Swelling rock advances into the underground opening because of expansion. It seems to be limited to rocks containing clay minerals.

c. *Rock Defects.*

(1) *Faults.* Fault describes a movement of the earth's crust which results in deformation (fig. 64). Where the earth's crust is broken into individual strips, faults may dip at a steep angle. Displacement may be up to several thousand feet deep and hundreds of miles long. Because they are places of rupture, faults have an effect on the whole rock mass in a particular area.

(2) *Folds.* These are zones where the rocks have been pressed into steep folds, which as a rule are more or less parallel to each other (fig. 65). Gentile folds

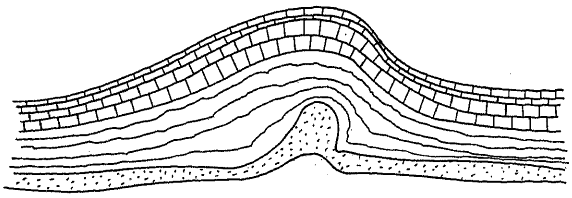


Figure 65. Folding.

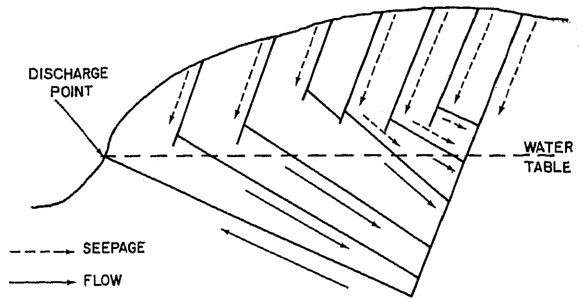


Figure 66. Water table in fractured rock.

are commonly symmetrical with reference to a vertical section through the crest, but where there is a one-sided lateral thrust, a fault may be formed.

(3) *Bedding planes.* Almost every stratified rock breaks along bedding planes. Bedding means that the materials are placed in layers bounded by planes approximately parallel to each other. The thickness of beds is on the average between 1 and 12 inches. If beds dip at an angle of more than 10 percent, or are thin and interbedded with incompetent beds, the rock mass is structurally weak.

(4) *Water pressure.* Figure 66 shows the formation of an apparent water table in a rock outcrop by seepage or infiltration above the actual water table (dotted arrows) and the actual flow upwards along fractures (solid arrows). Because of irregularity of fractures and discontinuity of permeable channels, there may be several apparent water tables in rock in close proximity.

74. Improving Conditions

a. Shoring and Lining.

(1) Shoring is done with timber or steel beams. It can be assumed that the vertical pressure on tunnel lining will be less than the weight of the overburden (somewhat independent of the depth) since a portion of this weight is taken up by the shearing stresses around the channel (A, fig. 67). In homogeneous rock the material tends to cave into the excavation and form a Gothic arch. If the shearing strength of a cohesive rock mass is great enough to absorb the vertical stresses, the tunnel may not require lining. Fissured and stratified rocks generally need lining. For design computations, the weight of the actual rock load exerting vertical pressure on the lining is replaced by an equivalent, uniformly distributed load, which is expressed in feet of overburden. This is commonly referred to as rock load. If the unit weight of the rock is 165 pounds per cubic foot (2,643 kg/cu m), the rock load of 20 feet (6 m) of overburden means a load of 165 x 20 = 3,300 pounds per square foot (1.6 kg/sq cm) on the horizontal projection of the tunnel. Typical rock loads are given in table XVII. For loadings from cohesionless materials, such as sand or crushed rock, (B, fig. 67) gives a rough estimate of the loading area. The thickness (h) has a maximum value of 0.6 (B + H), with decreasing values as the density of the material and the yield of the lining increase. By using the nomogram in figure 60 a workable solution for the shoring can be found.

Table XVII. Rock Load in Feet At a Depth of More Than 1.5 (B + H)

Moderately blocky and seamy	0.25 to 0.35 (B+H)
Very blocky and seamy	(0.35 to 1.10) (B+H)
Completely crushed, but chemically intact	1.10 (B+H)
Squeezing rock, moderate depth	(1.10+2.10) (B+H)
Squeezing rock, great depth	(2.10+4.50) (B+H)
Swelling rock	Up to 250 ft

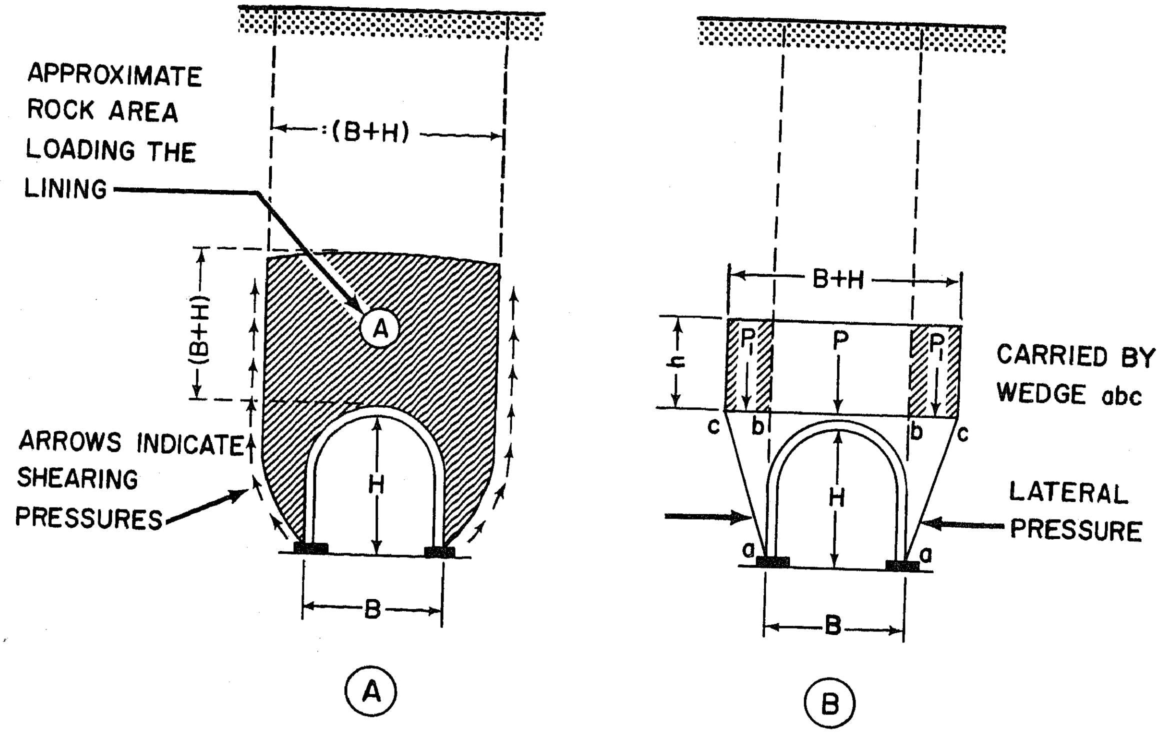


Figure 67. Pressure on a tunnel lining.

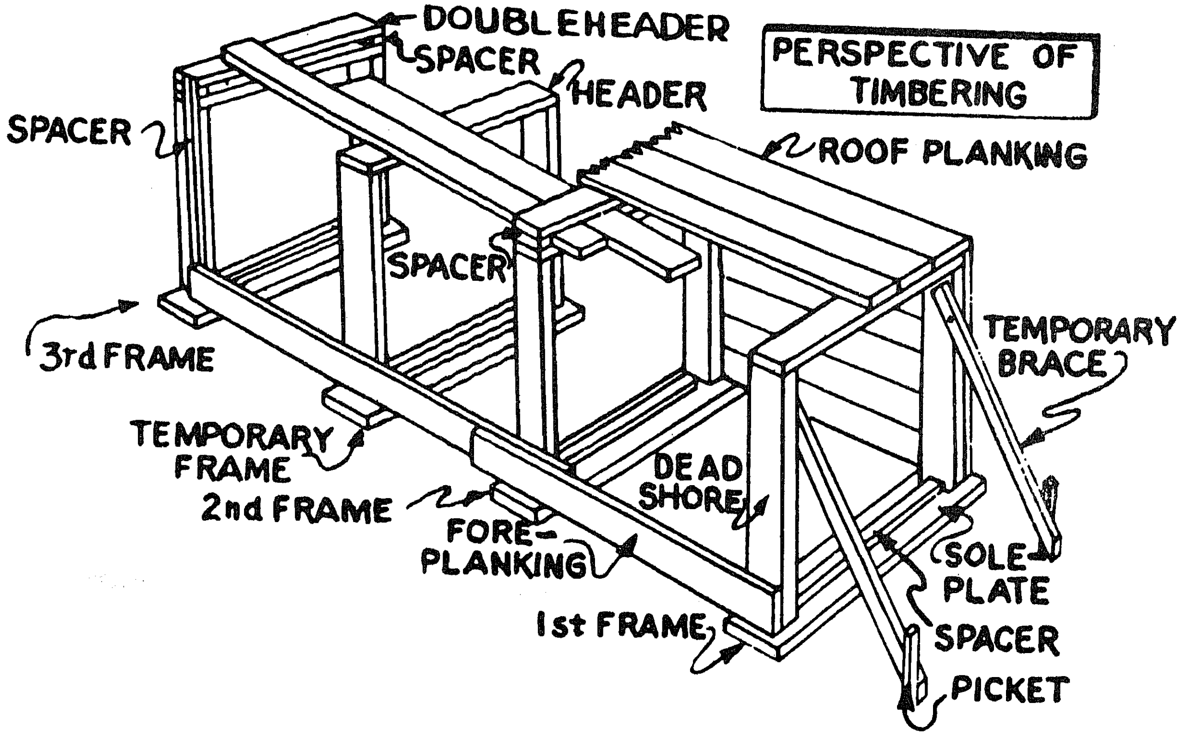


Figure 68. Square-set heading in dry, soft ground.

(2) Timber supports are generally frames, or sets, of timbers placed at variable intervals of 2 feet to 5 feet or more. The terms *plate, header,* and *spacer* are illustrated in figure 68.

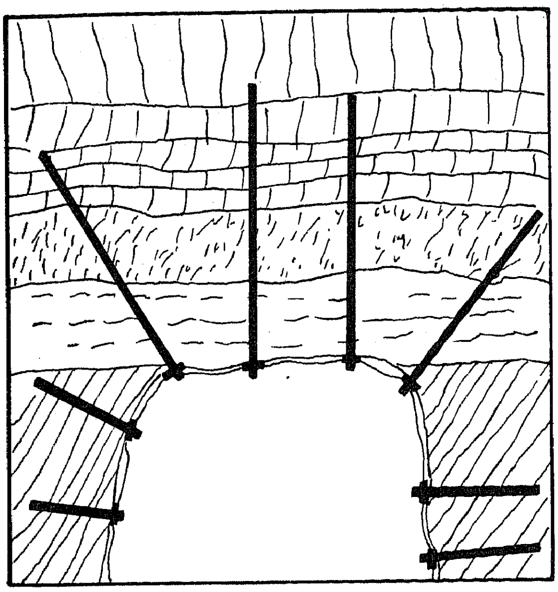


Figure 69. Method of roof bolting.

b. Bolting. Bolting is a way of support that ties the strata together with bolts so the full strength of the rock is used as support (fig. 69). Bolting has been used successfully where timber support has failed. This method is efficient in fissile or platy rock such as shales, slates, sandstones, or coal. In slabby or blocky rock, the bolts actually anchor the slabs or individual blocks to firm strata above them.

75. General Types of Underground Openings

Mines and tunnels are manmade, and the cave is generally natural. However, caves may be man improved, especially in those caves where the natural cavern has been developed as a tourist attraction. Mines, tunnels, and caves will be discussed individually, with another paragraph devoted to installation of blast-resistant doors or shafts in entranceways applicable to all three types (figs. 70–72).

76. Use of Mines as Shelters

a. Classification by Mineral Product. The best mines for conversion to shelters are those developed for mining metallic ores, limestone and other building products, and salt. The

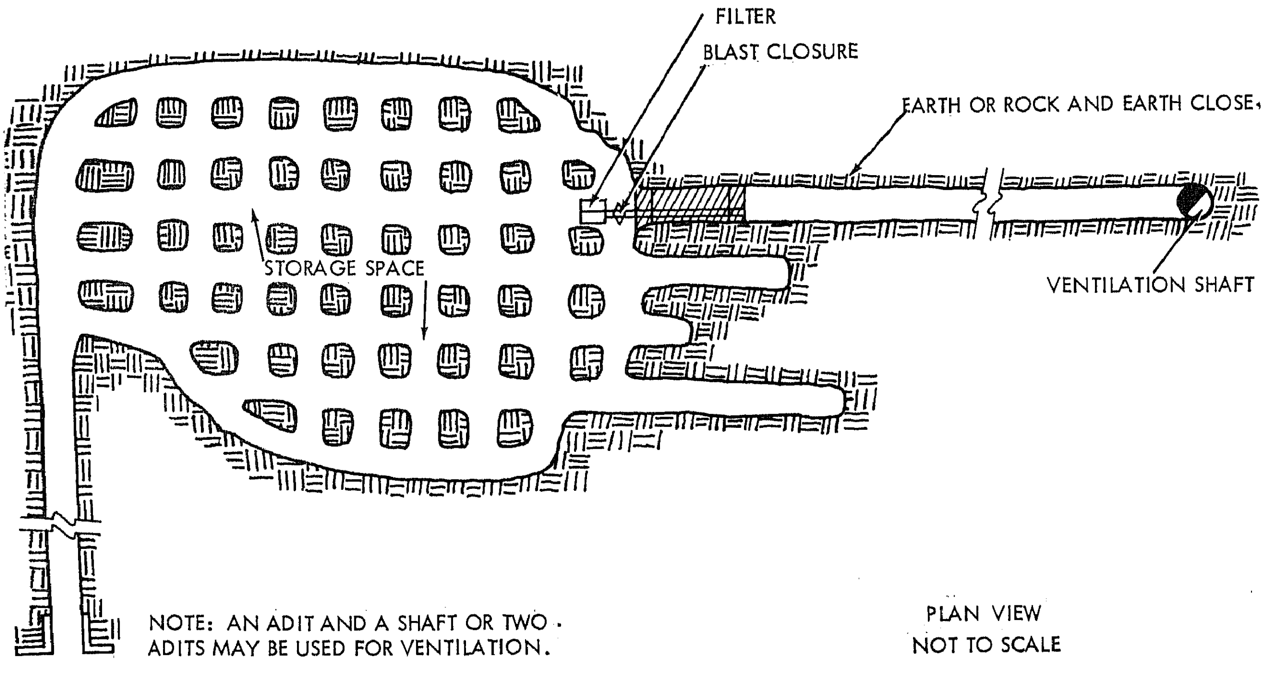


Figure 70. Room and pillar mining.

mines developed for coal and similar products cannot be used because of the common occurrence of noxious fumes and gases such as methane, the weak nature of the country rock (rock other than the ore-bearing vein), and the general developmental system. Mines where slates containing exposed sulfides are encountered should be avoided. Existence of this condition can be best learned by questioning miners or others familiar with the mine.

b. Classification by Type for Development. Developmental works in a mine are shafts, drifts, and entry tunnels (known in mining engineering as adits) and the organization of these works aboveground and underground. Mines which are only accessible by vertical or steeply sloping shafts and depend entirely upon hoisting machinery housed in a head frame for access to the mine are not considered usable as shelters. To convert such a mine to a shelter would require the construction of a blast-resistant semiburned structure to house a modified head frame and its associated powerplant, ventilating system, and entry system. This procedure is not considered within the capabilities of a troop unit nor is it considered economical in time or material requirements. In some

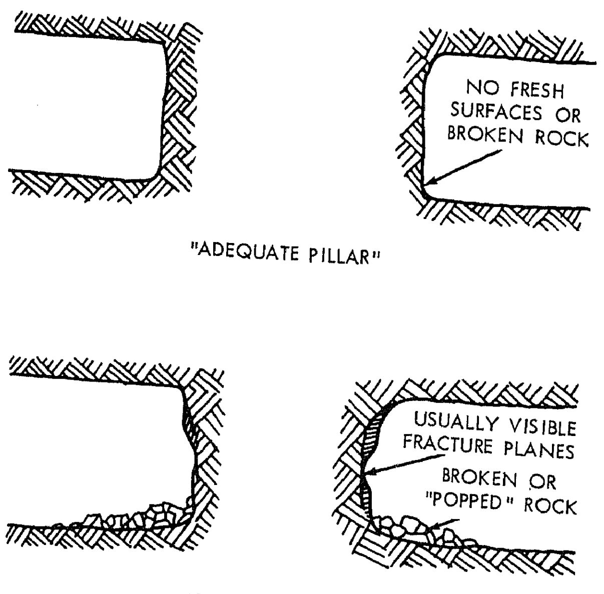
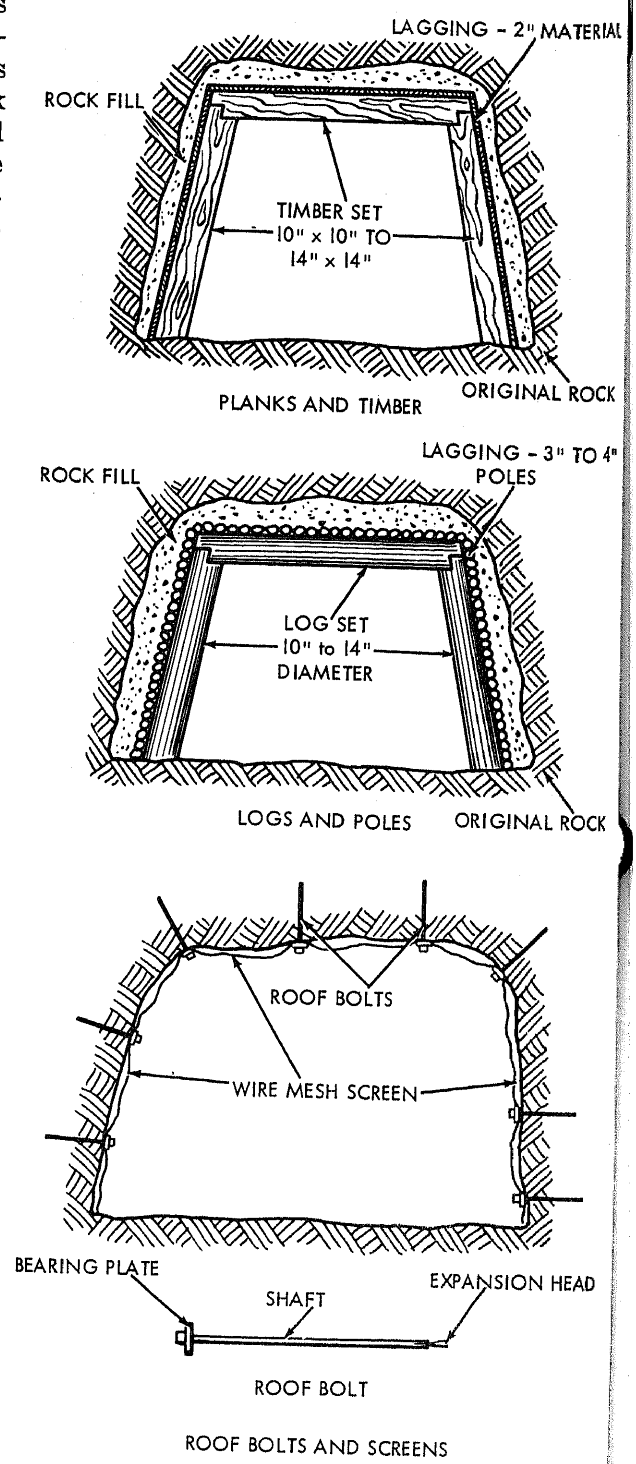


Figure 71. Mine pillars.



NOTE: THESE TECHNIQUES ARE STANDARD MINING PRACTICE AND ARE NOT INTENDED TO WITHSTAND OVERPRESSURE IN THEMSELVES. THEY ARE INTENDED TO PROTECT PERSONS AND PROPERTY INSIDE OF STRUCTURALLY SOUND TUNNELS FROM FRAGMENTS WHICH MAY COME LOOSE FROM WALLS AND OVERHEAD CEILING.

Figure 72. Tunnel and adit supports.

mines, in hilly country, the vertical shaft is used for removing ore and waste from the mine and for transport of miners, but the interior is also accessible by an adit or draft tunnel driven to a sidehill surface for ventilation, gravity drainage, or waste disposal. Those parts of such a mine accessible to this adit without the use of mechanical lifting or lowering can be used as a shelter.

(1) *Room and pillar mines.* This type of mining and its many variations are used in beds which lie horizontal or at slight to moderate dips, such as salt and limestone beds. Large areas are developed which are usable as shelter providing the pillars have not been robbed and the roof structure not caved (fig. 70). If pillars remain, although a large section has caved because of pillar removal, protection can still be obtained in the uncaved areas. A special check should be made in mines that have been allowed to cave to determine if any subsidence at the surface has taken place. This can best be checked by air drafts, by checking on the surface, and by close physical examination. The pillars must be closely examined for weakness and the area around the base for slabbed or popped fragments. When the pillars that have been left are too small in section and are not strong enough to support the overlying rock, they will progressively fail by slabbing or popping. Figure 71 shows the danger signs of weakened pillars. If only a very few weakened pillars exist in a mine and if they are not in one location near the adit or entry tunnel, the mine may still be used. However, the area adjacent to the weakened pillar should not be used, and one good pillar should be kept between the shelter area and the caving or potential caving area. In some salt mines that are very deep in the ground or where it is more economical to handle the salt in solution than in solid form, long rooms are made and allowed to fill with water to extract the salt, and the resulting brine is pumped to a central processing plant for recovery of the salt. This system produces exceptionally large rooms and if the geological structure is adequate above these rooms, they make most useful shelters.

(2) *Stoping.* This is another system used where the ore vein is on a steeper dip than veins where the room and pillar system is suitable although pillars in country rock may be left. Stoping is generally worked between two haulage drifts of differing elevation. If these haulage drifts open to the surface through adits they may be used. The stopes should be checked for loose rock, either ore or waste, and this removed. All loading chutes should be checked in a stope mine and emptied if the mine is to be used as a shelter. If this precaution is not taken, the heavy ground shocks transmitted through the rock could open chutes and drop loose rock into the shelter area. Long haulage drifts through country rock into the working veins are most favorable for storage. Due to expected complications in the open working area of the mine or near a vertical tunnel, the drift can be closed at the end of the usable portion by plugging it with waste.

(3) *Drift or adit tunnel linings and supports.* The common practice of timbering the haulage drifts and adits to the surface prevents caving and popping (fig. 72). The timber or steel sets should be very carefully examined for any failures. Repairs should be made and fresh stronger shoring installed before the mine is closed in for blast resistance. In fact, all work in the mine should be done before the door closures are put into position.

c. Methods of Closure for Blast Resistance.

(1) *Closure of adit or entry tunnel.* This is covered in detail in paragraph 79.

(2) *Closure of vertical or inclined shaft.* In mines where there is access through a secondary adit and it is necessary to close the vertical shaft,

this should be done by a flat structure composed of steel beams covered with timber and earth or a concrete slab capable of carrying the live load and surcharge of earth dead load above it. This slab design can be patterned from the slab for the concrete rectangular box shelter shown in figure 153, and the covering earth berm as shown in figure 126. If it would require more effort and material to close the vertical shaft at the top, and if access to this shaft is desired for ventilation, the drift or drifts being used can be plugged at the entry by waste rock at least two diameters deep at the top and the ventilating pipe run through the plug to the shaft. At least 2 feet of compact earth—not rock—must be placed on the outer side of this plug to prevent penetration of the stone plug, which will have structural strength but not be airtight.

(3) *Closure of subsidence openings.* Where the subsidence has taken place along a plane or fault and is clearly marked or takes the form of a clearly defined pit, it is feasible to close this opening with compacted earth. Where borrow is immediately available, it will only require dozing into the pit. Where it must be hauled to the site, it should be compacted in successive lifts. If drainage from the surrounding area will percolate through this fill into the mine shelter below, the water must be diverted from this fill. In any event, care must be taken that this fill is not saturated, as saturated soils do not attenuate shock.

77. Use of Tunnels as Shelters

a. Usable Forms. Tunnels are generally openings in the earth to permit vehicular traffic. They are generally level or have a moderate slope, and are open at two ends. Some tunnels are used for irrigation or water supply, but it is doubtful if these could be used as shelters. The usable form of tunnel will be a railway or automotive vehicular tunnel, or a pedestrian tunnel between large buildings. The continued use of automotive transport during combat makes it unlikely that traffic would be diverted to provide a tunnel for use as a shelter. However, if the tunnel is in or near a city the denser road net may permit this diversion. The use of railway tunnels may be more likely, particularly in areas where the rail line service has been driven out of operation by truck and bus competition. Railway tunnels are usually not lined so examination of the rock structure as described in paragraph 73 is possible. Snow-shed or rock-slide-shed type passageways under thin overhead cover on sidehills should not be classed as usable protective shelters due to their structural weakness and lack of thick overhead cover to attenuate shock and radiation. Areas where such structures are necessary are not stable and should be avoided for shelter if at all possible.

b. Preparation of Tunnel as Shelter. Examination of unlined tunnels may indicate areas of potential weakness disclosed by popping of stones or slabbing. Such areas should be examined by a mining engineer, if possible, or by one experienced in mines or geology. Generally this failure is not serious if not caused by excessive stress in the rock. Successive surface failure caused by dryness, nature of rock, or other factors, can be cured by rock bolting and heavy wire mesh.

(1) *Drainage and ventilation.* The drainage and ventilation systems must be thoroughly examined. Chimney type vents must be covered over with steel beams, or concrete slabs and earth, or plugged with a concrete and earth plug. Ventilation pipes to filters for the shelter should be inserted before the chimney vent is plugged. Incoming water drainage should be checked as to its source. If it is from a ground water source and is potable, this is indeed fortunate. If it is surface water percolating into the tunnel, then it must be diverted outside the tunnel, or if this is not feasible, then it must be captured and piped out of the tunnel.

(2) *Blast-resistant doors and hatches.* The fact that tunnels have two ends means that two plugs will be necessary. In general, one main door should be built

and one emergency exit constructed at the other end. This emergency exit need not be an operable door or hatch but a simple crawl tube through the earth fill plugged with sand and sandbags. In some cases a large vehicular door may be built at one end and a personnel hatch or walk-through door at the other. General plans of such arrangements are shown in this chapter and details in chapter 6.

78. Caves As Protective Shelters

A cave or cavern is an opening produced by nature in the solid crust of the earth. Caves are principally found in limestone and gypsum as a result of the solvent action of ordinary circulating underground water. Less often they occur in sandstone, and in volcanic rocks such as basalt, lava, and tufa. The form of the caves depends partly upon the nature of the substance in which they exist, but is frequently altered by external causes. Those in limestone and gypsum are unquestionably the results of the dissolving of water, and those in trachyte and lava appear to be the effects of gas.

a. Exploration and Reconnaissance. Caves which are well known and have been developed as tourist attractions are generally usable. The inspection party should include a mining engineer or geologist, and, if possible, natives familiar with the caves. Exploration of little known caves is a popular sport in almost all countries and in the United States is known as spelunking, a word taken from speleology, the scientific study of caves. If a speleologist or spelunker who is familiar with the cave in question can be found, much time can be saved in exploration and reconnaissance. In most countries there are speleological clubs which maintain a file of maps and drawings of all known caves. This is a definite asset in locating such natural features. In all cave reconnaissance where the cave parallels the surface of the earth, a careful reconnaissance of the surface for subsidence into the cave must be made. The exploration must include a search for all openings to the surface. An estimate must be made of the runoff of water from the cave. The structure of the overburden must be carefully examined and weak spots detected and corrected by methods noted previously for mines and tunnels.

b. Conversion of Cave to Protective Shelter.

(1) *Water.* The biggest problem normally associated with caves is the large amount of water flowing constantly from the cave. This may require a special structure to prevent a blast-induced backflow at greater velocity into the cave. If it is possible to enclose the flow in concrete pipe or corrugated culverts and bring them to the surface with an adequate head of water to offset the anticipated blast overpressure, the problem is greatly simplified. If, however, the required head is not available or cannot be produced, it becomes necessary to check valves of a large outside flap design with multiple pipes through a concrete dam headwall. These flap valves are simple to make and are rugged enough to take a very heavy shock wave. If the construction of large-diameter flap valves is attempted, then they must be designed with structural shapes on the order of those shown for blast doors.

(2) *Ventilation.* Caves in gypsum sometimes have foul odors as do those where sulfur deposits are uncovered by erosion. The solutions to the ventilation problem in caves are similar to those in mines and tunnels.

79. Entrance Structures In Mines, Tunnels, and Caves

The problem peculiar to each of the above types have been discussed in paragraphs 72 through 78. The closure of entrance tunnels with blast-resistant entry doors or hatches is common to all three types of subterranean opening.

a. Vertical Shaft and Hatch in Earth Fill. Of all tpes of entrance arrangement, this is the simplest in construction material. Figure 73 shows a compacted earth fill in front of the mouth or portal of a mine adit, or a tunnel or cave portal, with the fill resting on a natural leveled area or one built up at the time of orig-

inal construction by use of the waste material from the mine or tunnel. If such a bench or level space does not exist, then the fill at angle of repose of the earth must be placed partly into the mouth of the tunnel. Care should be taken that the horizontal bench containing the hatch does not extend into the tunnel as this will result in the hatch being subjected to reflected pressures of unknown magnitude. The horizontal hatch cover shown in figure 73 will be subjected to reflected pressures resulting from the shock front striking the inclined and vertical faces of the natural and excavated rock and the inclined faces of the fill.

b. Personnel Walk-Through Door. This arrangement, next simplest in construction to the horizontal hatch, is very useful for handling supplies, litter cases, or equipment that can be passed through a 2-foot 8-inch door. This arrangement requires the construction of a concrete box door frame to hold the steel door. The frame must withstand overpressures on the order of 200 psi (14 kg/sq cm) developed with a slideon overpressure of 50 psi (3.5 kg/sq cm) on horizontal surfaces. The door may be placed on the inside of the box facing the interior of the box if the tube or entrance tunnel from the interior to the box is too small to permit the door to swing out. If this is done, the roof and floor slabs should be extended to meet the solid rock of the tunnel or adit wall and transmit the resulting thrust on the door to the walls of the tunnel. The box is placed with the solid portions broadside to the compacted fill

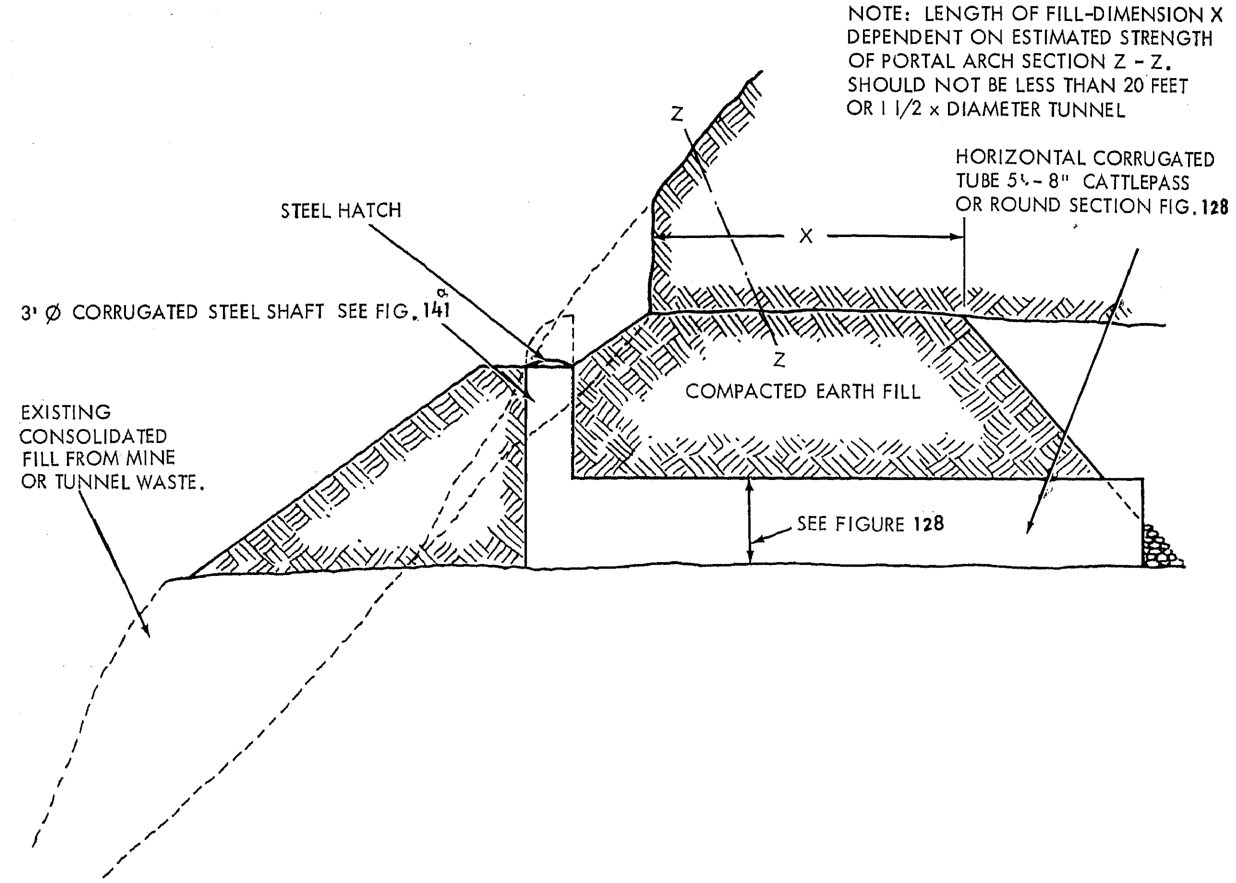


Figure 73. Combination vertical and horizontal culvert entry for mine, tunnel, or cave.

to be supported against horizontal thrust by that fill. If a double door arrangement is required, doors can be mounted on both positions, thus insuring that one door will be closed at all times. However, if litter cases are to be passed through the doors, the box will have to be made larger and must be more heavily reinforced.

c. Massive Drawbridge Door. This very powerful and heavy door is used for the passage of small vehicles, equipment, missiles, and major items of equipment requiring a door 6 feet high and about 10 feet wide. The fixed dimension on this design is the 6-foot vertical dimension and the width of the door may be varied in 1-foot increments. It should not exceed 10 feet in width, however, as the design of the concrete frame is based on this width. The double tunnel with a pedestrian passage parallel to the vehicular passage is intended to avoid frequent use of the large drawbridge door which requires a chain hoist to raise and lower. If the construction required for the large door is entered into, the one or two small door frames and doors are a small additional problem. This door is not easy to construct and requires a great deal of ½-inch steel plate and heavy structural shapes, and the welding must be of high quality throughout. If the precise shapes specified cannot be obtained, other shapes, with an equal or higher section modulus, may be used. Spacing greater than an unsupported 6 inches of ½-inch plate between beam flanges must not be permitted if a deeper and narrower shape is used. This door is a major undertaking for an engineer troop unit, and it must be fully justified by actual need before its construction is approved. The frame is of very heavy reinforced concrete and in turn must be keyed into the bedrock of the tunnel. Bearing must be against bedrock, not paving, lining, or other materials, as the horizontal thrust of this door is about 1,400 tons (1,270,080 kgs). If the rock is not solid at the point of placement of the door, the bearing tables normally used in bridge abutment design should be used. A qualified civil or structural engineer should design or check the design of the site adaption of such an arrangement, especially if any modifications in the design are proposed.

CHAPTER 4

CRITERIA FOR THE DESIGN OF SHELTERS

Section I. CRITERIA FOR PROVIDING NUCLEAR PROTECTION

80. General Nature of the Problem

a. Factors for Consideration. Because of the unusual nature and magnitude of the blast forces, the problems of blast resistant design differ from those with which the engineer is usually faced. The behavior of a structure under so-called "static" loads, or under very slowly applied loads, is quite different from the behavior of the same structure under rapidly applied loads, such as those which arise from wind gusts, earthquakes, or blasts from explosions.

b. Loadings. Many engineers treat dynamic loads by a procedure which relates to "equivalent" static loads. This involves difficulties when the structure is loaded to a range near the point of collapse. A static load above the yield resistance of a structure would cause the structure to fail, but a dynamic loading with a transient peak above the yield value may not necessarily cause it to fail. With only a slight modification in the concept of an equivalent static load, a workable design procedure can be reached. This modification involves the idea of a limit load or limit resistance; the structure is thus designed to have a particular strength or resistance.

c. Choice of Structure. The first choice is the type of structure. Should it be above ground, partly buried, or below ground? Should it be closed in order to shield the interior of the building, or open, with light, frangible siding that permits the blast to enter and pass through? The forces acting on the structure and on its component parts differ greatly for these differing types.

d. Protection. The protection can be stated in terms of the distance from the burst at which the structure is intended to survive. The force on the structure may differ from overpressure as will be explained below (para 81). The duration of the force depends on the yield of the weapon.

81. Types of Dynamic Loading

a. Comparison of Nuclear and Conventional. Structural design for nuclear blasts requires consideration of rapid, transient, and lateral loads (different from those used for conventional design) called overpressure. Where conventional construction may require design for 4 psi for a warehouse floor, for example, structures to resist a nuclear blast can be designed for 10, 100 or 1,000 psi (0.7, 7, or 70.4 kg/sq cm). Furthermore, little correlation exists between nuclear blast resistant design and that for conventional weapons. Designs of structures to resist conventional weapons consider penetration of a projectile or its fragments and the effects of high explosives (HE). Nuclear weapons have no shattering effect, fragmentation, or penetration.

b. Overpressures. While HE detonations may develop very high overpressures, the pressures are localized and of short duration, with fragmentation and shattering the predominant effects. The principal effect of a nuclear detonation upon a structure is overpressure, which suddenly rises to a peak and then decays in such a manner that the entire structure will be loaded for a measurable length of time. The structure must be built to withstand this overpressure. The distance from the detonation, the depth of burial, and the size of weapon yield may cause the overpressure to decay rapidly or slowly in relation to the response time of the structure. The development of the Mach Stem magnifies the overpressure. A structure above-

ground responds not only to the overpressure, but to reflected and dynamic (wind load) pressures. These pressures are developed when the blast wave interacts with a surface in its path. The extent of amplification depends on the peak side-on overpressure and the angle of incidence of the structure to the blast wave. Figure 12 shows these relationships. When a blast wave is channelized, or strikes an interior corner, it may be magnified many times by reflection. In addition, when the blast wave envelops and passes around aboveground structures, the actual mass of air in the blast (or shock) front and in the following compressed air has a velocity which causes a drag. This is similar to a wind load.

c. Negative Overpressure. Another feature of a nuclear blast which is negligible in HE detonations is the development of large negative overpressure. It may be as low as 5 psi below atmospheric pressure, causing an outward load on the structure as it passes because of the higher pressure inside. These negative pressures may cause additional damage to aboveground or near-surface structures. Therefore they must be considered in protective structure design by adding weight or resisting moment capacity to a structure for these forces.

d. Effects on Aboveground Structures. The combined effects of overpressure drag forces, and pressure reflections on aboveground structures reduce the usefulness as blast protection of that type construction. Other effects that could affect aboveground contruction are low initial radiation and fallout radiation protection.

e. Effects on Semiburied and Buried Structures.

(1) A semiburied structure built with a raised earth embankment may be loaded by large reflected pressures from the sides of the berm transmitted to the structure. A fully buried structure is flush with the surrounding surface, eliminating reflected and drag pressures. The negative pressures upon the depth of burial and type of structure. A negative pressure of about 4 psi (281 gr/sq cm) or less is assumed to be a maximum that would be encountered under most conditions. A net negative pressure of at least 1/2 psi (35.15 gr/sq cm) would probably be required for a damaging upward force within the structure. Loads on entranceways are not likely to affect the structure of the passageway. The entrance closure and its foundation, however, must be designed for the effects of negative overpressure in the passing blast wave.

(2) Tests have indicated little reduction in overpressure for small depths of burial. High overpressures may be transmitted to the roof and sides of a buried structure. The compaction of the earth fill becomes extremely important. The load for which a buried structure must be designed is a result of the interaction of the soil in the fills and the structure. There is no significant increase of pressure due to reflection at the interface between the soil and a buried structure. Therefore the free-field pressure (pressure in the soil caused by the blast wave), regardless of its direction, is the upper limit of the pressure on the structure. If the structure is more deformable than the surrounding soil, the pressure transmitted from soil to structure will be lower than the free-field pressure. The structure deflects away from the load, causing the "arching effect" where the soil transmits part of the pressure *around* the structure rather than *through* it.

(3) The concept of arching (fig. 74) is directly related to the flexibility or compressibility of the buried structure. If the structure is highly compressible, it acts like an open hole. The structure readily deforms and the loading passes around it through the mechanism of soil shear. Thus the structure receives negligible loading, while the soil itself bridges the load. If, however, the structure is quite rigid (such as a reinforced concrete box), the loading it must resist may be even larger than the free field pressure in the surround-

ing soil. As the compression of the soil transmitting the blast overpressure progresses downward, the roof is initially loaded and must carry the soil directly overhead and the over-

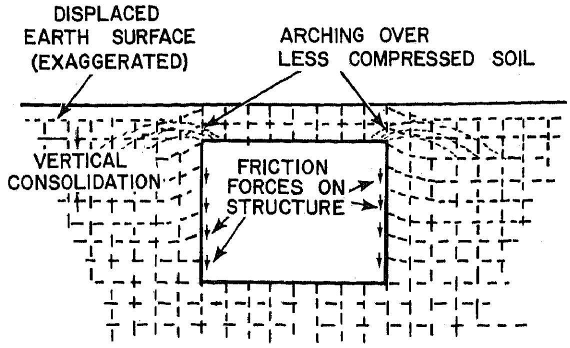


Figure 74. Arching action developed by soil consolidation.

pressure. It must also carry the in creased load as the soil that surround the structure continues its downwar movement and drags on the halte mass of the soil that the structur supports. Figure 74 illustrates thi drag and the arching of the load ont the structure. The magnitude of th force that is transferred to or from structure by arching is directly re lated to the shearing strength of th soil and the rigidity, or flexibility, o the structure. It is very difficult t predict theoretically and assumption must consider a wide variety of un knowns. A design procedure shoul be similar to that shown in figure 67

(4) The buried arch is initially loade asymmetrically regardless of th depth at which it is buried. Figure 7 graphically represents this loading This illustration shows that one sid

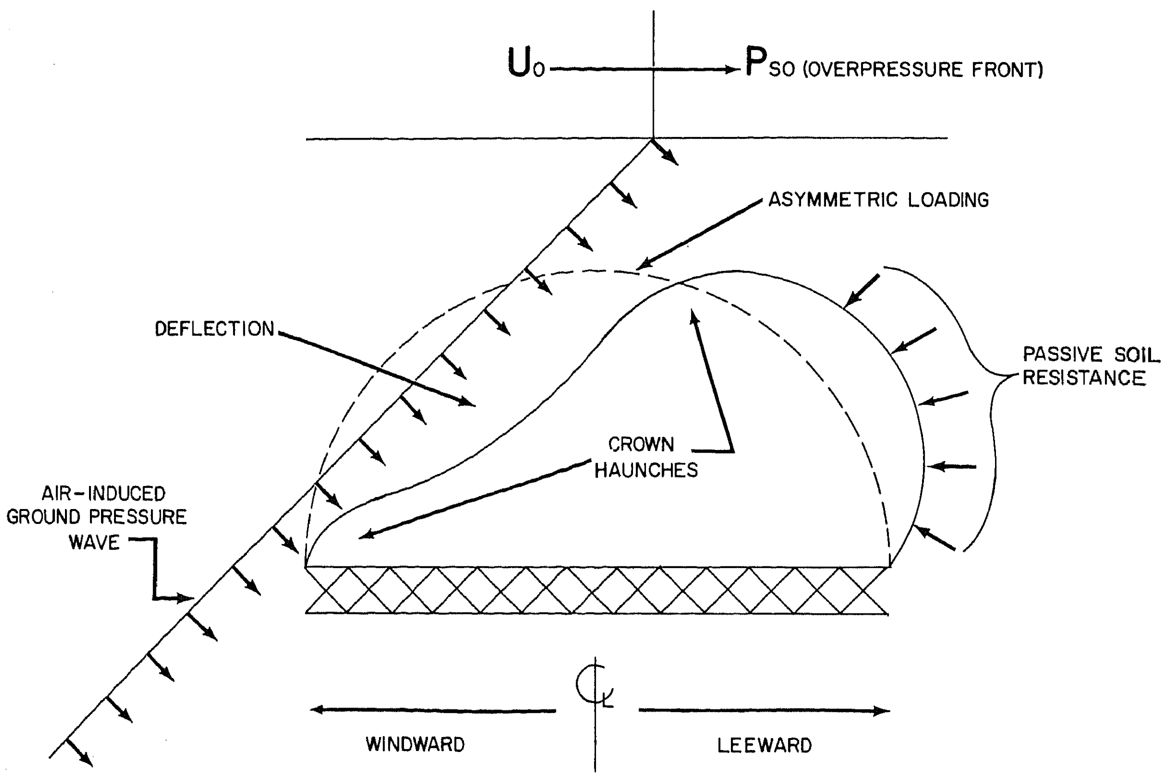


Figure 75. Development of friction forces on arch structure by soil consolidation.

of the arch is subjected to loading before the other side, as one side deflects inwardly, the other side is forced in an outward direction against the soil. When the side deflects outwardly the soil must be moved, and the passive restraining force of the soil is developed. As the overpressure pulse engulfs the arch, a similar deflection occurs at the crown. The crown deflects in an outward direction into the soil, and the load distribution around the arch equalizes.

82. Structural Response to Static and Dynamic Loads

a. Structural Design.

(1) Conventional structural design is primarily concerned with transferring known or predicted gravity loads to the earth from some position in space by a system of structural members without exceeding allowable stresses. Nuclear blast resistant design must provide strength to resist forces normal to structural surfaces, gravity loads, frictional loads caused by settlement of earth fill, and even upward loads acting upon the foundations of floors of the structure. The blast loads from a nuclear explosion are characterized by a sudden rise in pressure, a gradual decay, and a negative pressure of possibly longer duration. An idealized airblast overpressure curve is given in figure 76.

(2) The rapidity with which the loads are applied and the type of response of the structure are such that structures must be designed to withstand both the externally applied loads and the momentum developed in the structural elements themselves. Compare this with the spring of a scale which must be able not only to support the weight of the scale and its contents, but must overcome the dynamic loading which results when the mass is applied and the system seeks equilibrium. Similarly, it is necessary to consider the strength necessary for a roof to resist

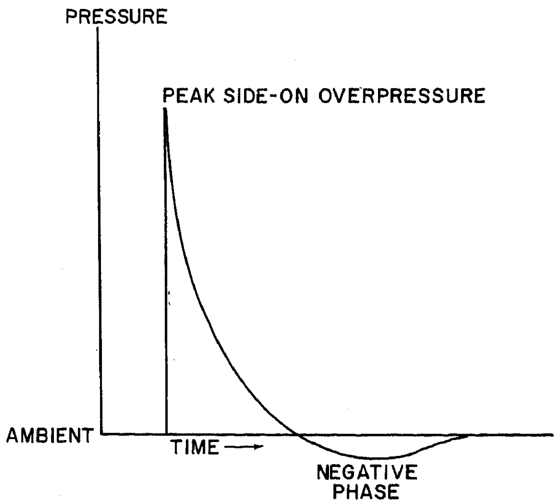


Figure 76. Idealized airblast overpressure curve.

the overpressure as applied by the blast plus the weight of the roof itself. Also, the loads created by the mass of the roof system, having been accelerated under the force of the overpressure, consequently require deceleration. Deceleration requires strength of possibly the same magnitude as that needed to resist the overpressure itself. The duration of the positive pressure of the blast wave, therefore, becomes a critical factor in determining the maximum load which a structure must withstand. This duration is compared to the time of the elastic response of the structure and the amount of the elastic response of the structural members in relation to their elastic yield point. The elastic response time (related to stiffness) of the construction materials used in underground structures is so short in comparison with the positive pressure phase of a nuclear detonation that the latter can be considered of infinite duration without significant error. Figures 77 and 78 illustrate these effects. The figures are dimensionless in that the displacements shown in each figure are related to a single line which represents the displacement under a

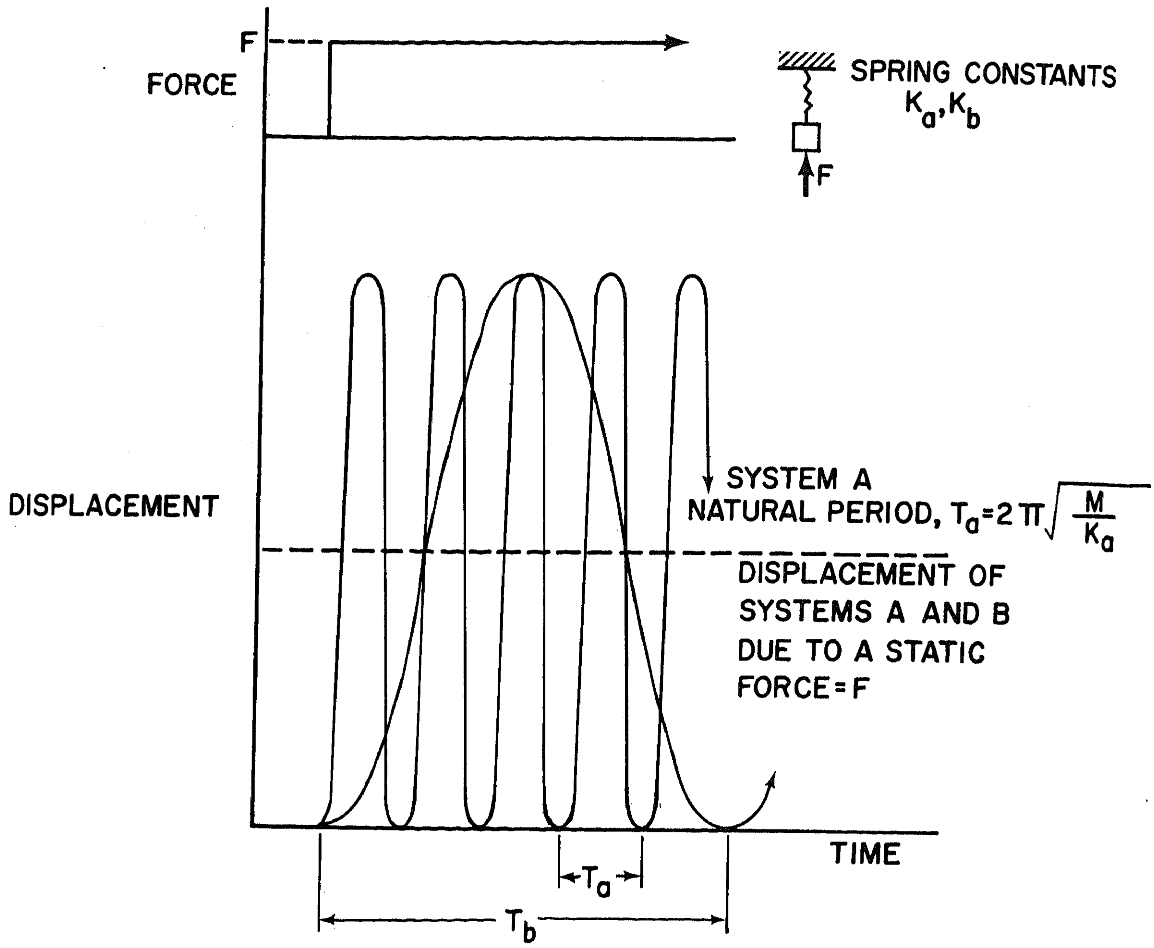


Figure 77. Fundamental response of undamped long- and short-period systems to a step loading.

specified load. The rise time for the peak overpressure for such structures, however, is so short that a magnification occurs in the response of the structure. The response is greater than it would have been had the same overpressure been gradually applied over a long period of time.

b. Selection of Material for Construction.

(1) The structural response to the application of overpressure becomes an important criterion, not only in the determination of structural strength requirements, but in the selection of material for construction. *For example,* a concrete structure in an arch shape may have a critical response (When failure is most likely to occur) that takes place when the structure is rebounding after it has first absorbed, in the compressive phase, a large amount of elastic energy. In this respect, a design that makes use of the compressive strength of concrete may be faulty since tensile stresses develop that are not considered in conventional design.

(2) An important design factor for dynamic loads is that materials of construction exhibit markedly different properties under high rates of loading. Materials such as timber and steel have strengths in the elastic range under high rates of loading which are 25 to 50 percent higher than those

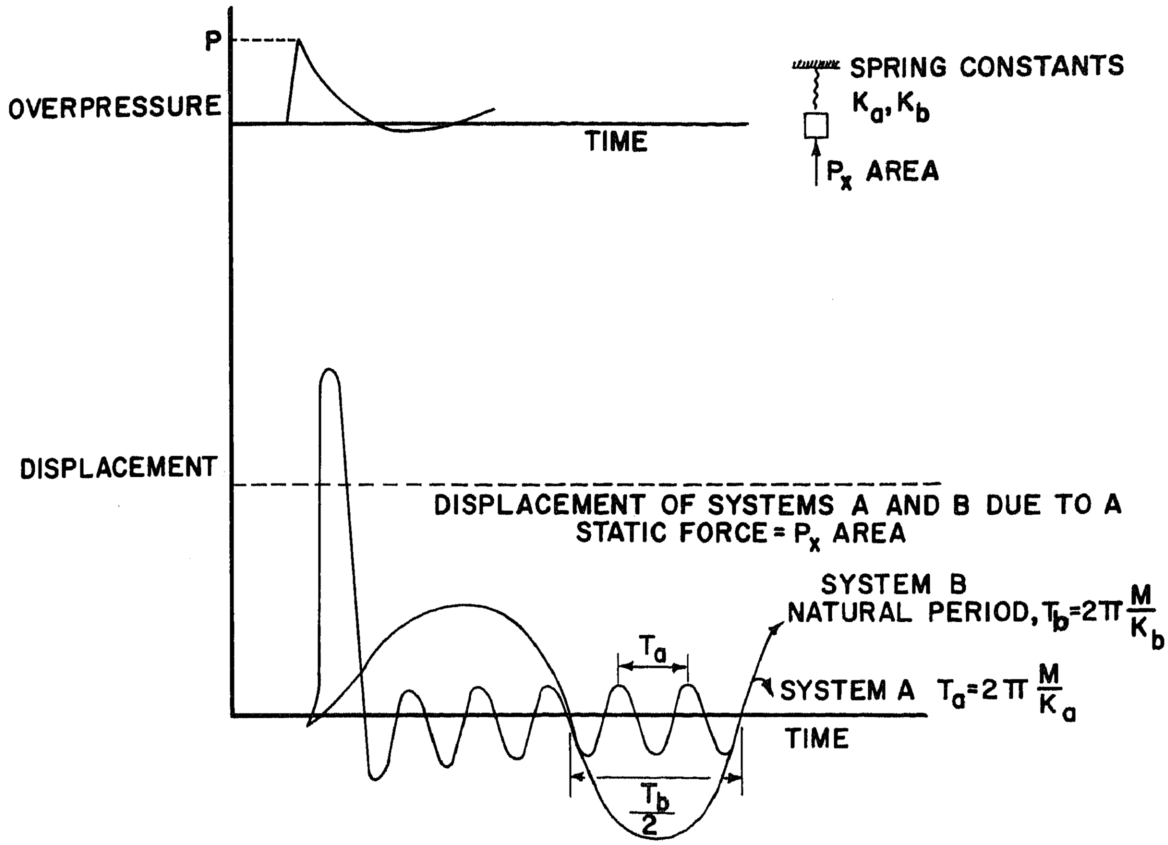


Figure 78. Fundamental response of undamped long- and short-period systems to a blast pulse.

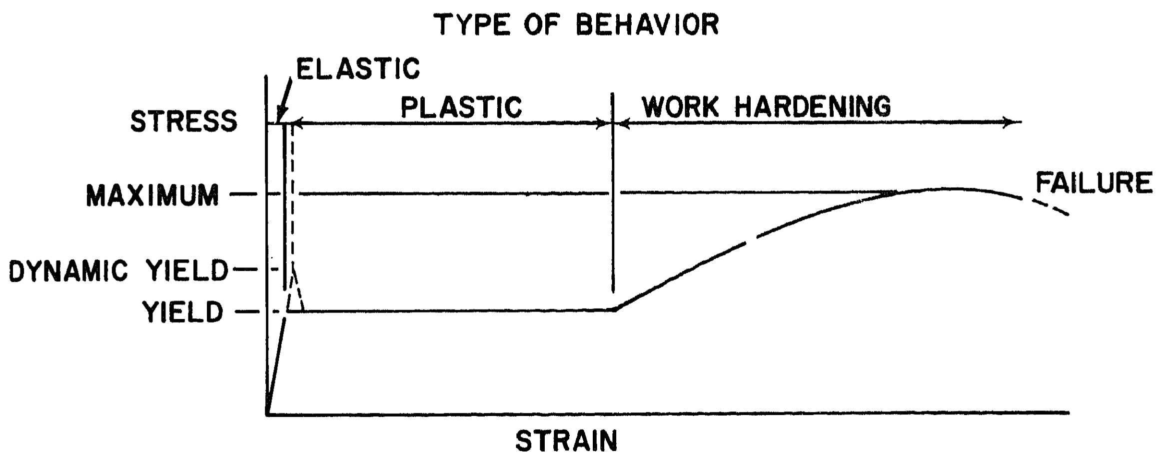


Figure 79. Idealized stress-strain relationship of intermediate grade steel.

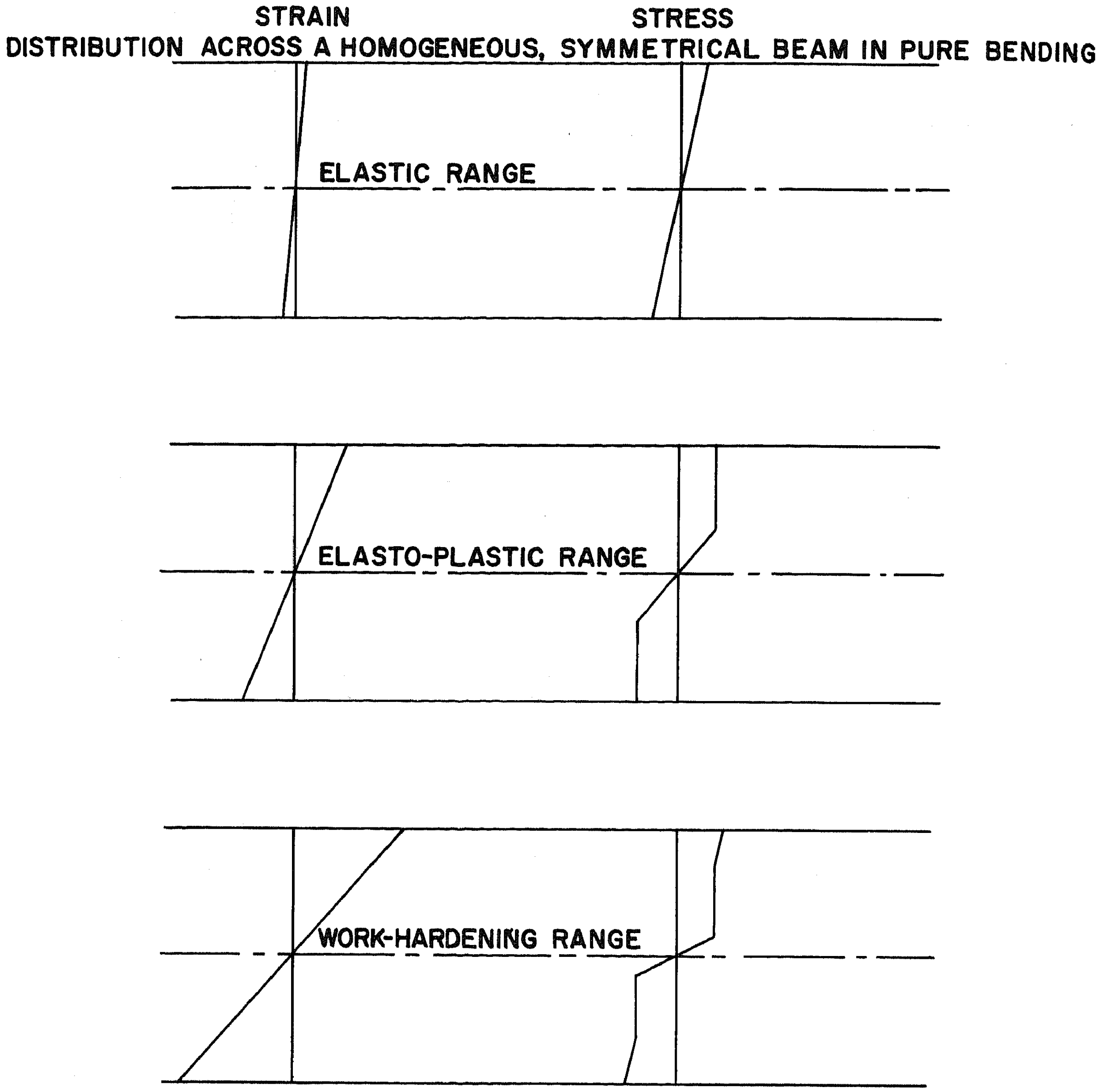


Figure 80. Distribution of stress and strain across a beam in pure bending.

available when the loads are applied gradually. *For example,* the yield point of A–7 structural steel (approximately 32,000 psi, or 225 gr/sq m under static load) may be increased to 45,000 psi (316.4 gr/sq m) under rapid loading. Even greater dynamic strength characteristics are obtained in timber under rapid loading. These characteristics allow the designer to use the dynamic strength available in steel or timber to withstand the high pressure which occur in a sharply peaked overpressure pulse.

c. Elasto-Plastic Action. Another design factor for dynamic loads is the elasto-plastic behavior of the structural sections. The plastic strength of the structural elements may be used in the design. The design allows for the dynamic characteristics of the load by making use of the capability of the structural material to

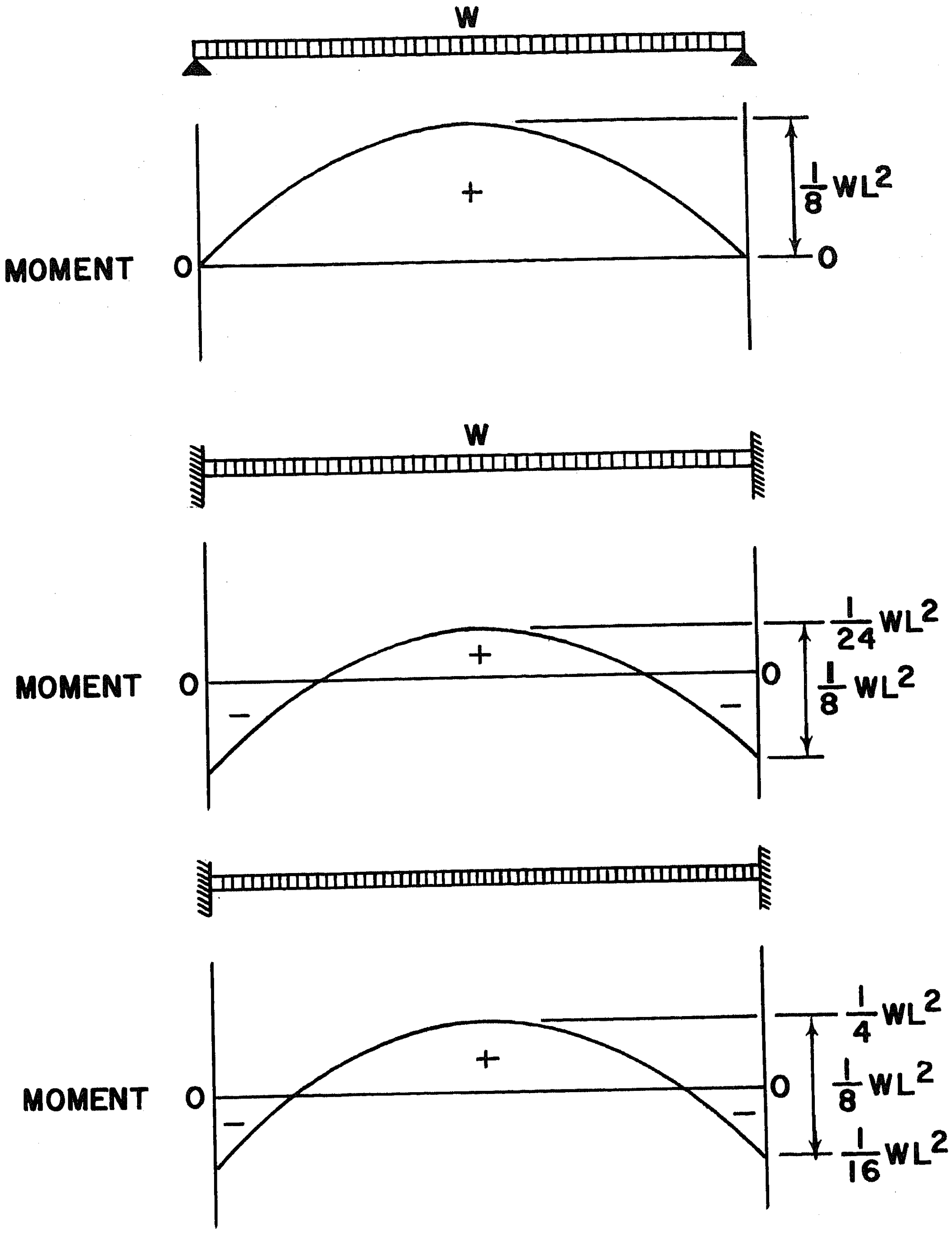


Figure 81. Effect of plastic hinges upon the moment distribution along a beam.

absorb some of the effect of loads of short duration by behaving inelastically. The response of the structural system to the application of the overpressure is absorbed by plastic deformation of the structural elements. These deformations dampen the response and take such a length of time that the system is brought to rest before the ultimate strength of the sys-

tem is reached. This concept also permits the use of the lower design moment values for the beam-type structural elements by considering failure to occur when a collapse mechanism is formed. Plastic hinges develop at the point of maximum moment. When enough hinges develop to make the structural system unstable, a collapse mechanism is formed. These effects and concepts are illustrated in figures 79 through 81.

Section II. CRITERIA FOR PROVIDING CB PROTECTION

83. Objective

In preparing a shelter to protect against chemical and biological contamination, the principal objective is to provide a space of enclosed air which is resistant to infiltration of CB agents. This objective can be achieved by one of two methods—either sealing completely to insure airtightness or providing a filtering system which can purify air going into the shelter while maintaing a slight overpressure inside. Because the CB protection capability will normally be integrated into a shelter primarily designed or improvised for protection against conventional or nuclear weapons, materials and methods for construction will not be changed, and the selection of such will be made according to the degree of protection desired against nuclear or conventional weapon systems.

84. Protection By Sealing

If the shelter is to be sealed completely, initial consideration should be given to construction or selection of a facility which, by itself, is relatively airtight. Any apertures or entrances to the facility should be closed and strengthened to resist blowout during an attack which, if it occurred, would readily introduce contamination into the sheltered area. All holes, cracks, and openings should be sealed or calked with materials such as calking or asphaltic compounds. It no other material is available, masking or similar tape will provide adequate seal. Putty and mud which shrink upon drying are not generally satisfactory. Major sources of leakage will be windows and doors, surface intersections, electrical and plumbing inlets, and faults in continuous surfaces such as walls and ceilings. If shelter is provided, it is essential that personnel realize the undesirable effects caused by a stagnant air supply on the human environment and the fact that once the seal is destroyed, the occupants will need to revert to individual protective equipment.

85. Protection By Filtering

If the CB protection capability is to be provided by using filtering equipment, initial consideration should be given to the equipment necessary to develop a slight overpressure and the ability of the facility to maintain it in the inclosed area. The overpressure should be on the order of 0.5-inch water which will be sufficient to insure that any leakage in the facility will be from inside to outside. The Chemical Corps supplies filter units of various sizes for military use which are capable of providing protection against field concentrations of all known CB agents and of removing particles of radioactive matter. The filter units are discussed in the following paragraph. In addition, the facility to be developed should be selected and modified in a manner similar to that for the unventilated shelter—providing all measures possible for insuring airtightness.

86. Filter Units

There are two basic types of filter units—particulate and particulate-chemical. Classification of particulate units can further be broken down into those of a general purpose type, such as those used as prefilters in ordinary air conditioners or heaters, or those of an absolute type which have an additional capability of removing virtually all dust and particles which could carry radioactive matter or biological agents. The particulate-chemical filter is of an absolute type only. It is capable of removing toxic chemical agents by absorption into activated charcoal and, in addition, of trapping radioactive particles and biological agents. The Chemical Corps filter units are all of the particulate-chemical type, and provide a range of airflow rates from 300 to 5,000 cubic feet per

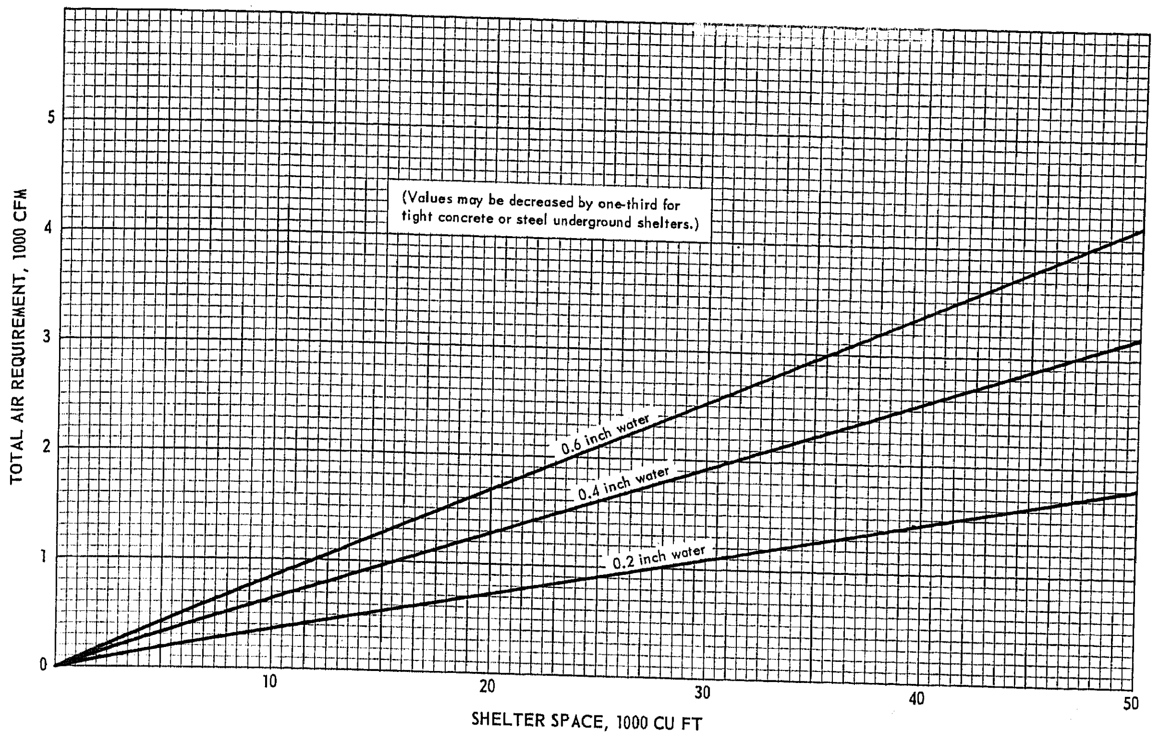


Figure 82. Estimated air required to pressurize sealed shelters.

Table XVIII. Specifications of Standard Filter Units [1]

Filter unit [2]	Voltage/phase (60 cycle)	Kilowatts (approx)	Filter [3]	Output capacity (cfm)	Weight (lb)	Dimensions (inches)
ABC-M6A1	115–230/1	1¼	2-M9A1 particulate 2-M10 gas	300	400	34 length 24 width 39 height
M9A1	208–220–440/3	1¼	ABC-M14 gas-particulate	600	800	116 length 30½ width 34 height
M10A1	208–220–440/3	2½	ABC-M15 gas-particulate	1,200	1,200	158 length 42 width 39 height
M11	208–220–440/3	6	ABC-M16 gas-particulate	2,500	1,700	171 length 55 width 39 height
M12	208–220–440/3	10	ABC-M17 gas-particulate	5,000	2,800	195 length 53 width 58 height

[1] These filter units are specifically designed to remove toxic chemical agents, biological agents, and radioactive particles from incoming air in continuous operations.

[2] All filter units are available with gasoline engine in place of electric motor.

[3] All filters are credited with a total life of 100 units.

minute (8.5 to 140 cu m/min). This type equipment is normally class IV and issued when authorized by the theater commander. Figure 82 can be used to estimate the air required to pressurize a protective shelter. The various size units are listed in table XVIII. The three basic configurations of the units are shown in figures 83 through 85. Performance characteristics are

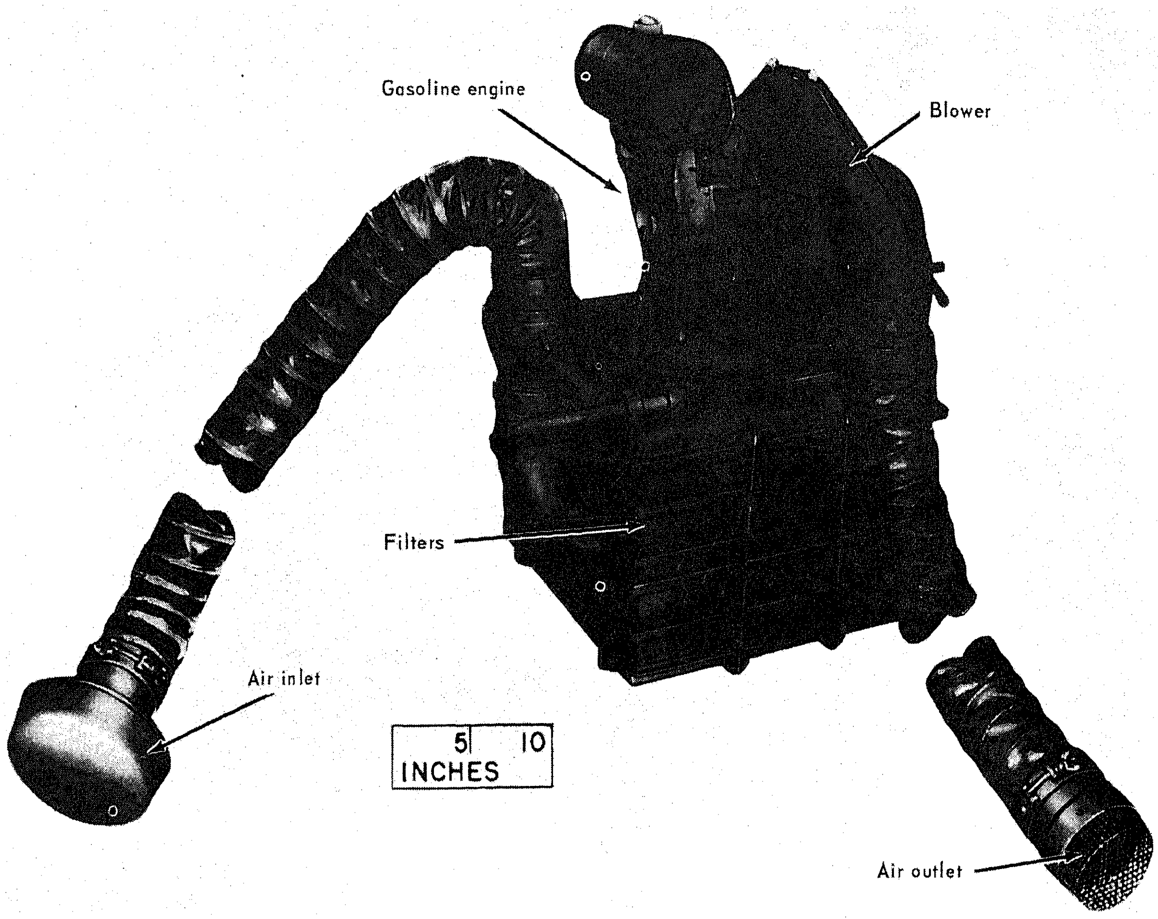


Figure 83. ABC–M6A1 gas-particulate filter unit.

shown in figures 86 through 89. The units do not provide protection against carbon monoxide.

87. Emplacement of Filter Units

a. Filter units should be installed in a readily accessible location with sufficient clearance around the unit to provide for periodic removal and replacement of the filter elements. Since the elements collect contaminants and in no way neutralize them, they become a source of contamination, and extreme care should be exercised during handling. Also, the elements can become a very hazardous radioactive source within the shelter and it will be necessary that shielding be provided around the unit. The easiest way to provide shielding is to install the unit below floor level in a pit and place sandbags or concrete blocks over the access hatch. If the unit must be installed at floor level, the following criteria can be used to determine the amount of shielding necessary.

(1) For air intake system of 100 cfm (2.82 cu m/min), provide a mass thickness* of 40 to 60 psf (200 to 300 kg/sq m).

(2) For 1,000 cfm (28.2 cu m/min) provide a mass thickness of 80 to 120 psf (400 to 600 kg/sq m).

(3) For 10,000 cfm (282 cu m/min) and greater, provide a mass thickness of 160 to 240 psf (800 to 1200 kg/sq m).

b. If practicable, the air inlet to the filter

* See paragraph 49 for definition of mass thickness.

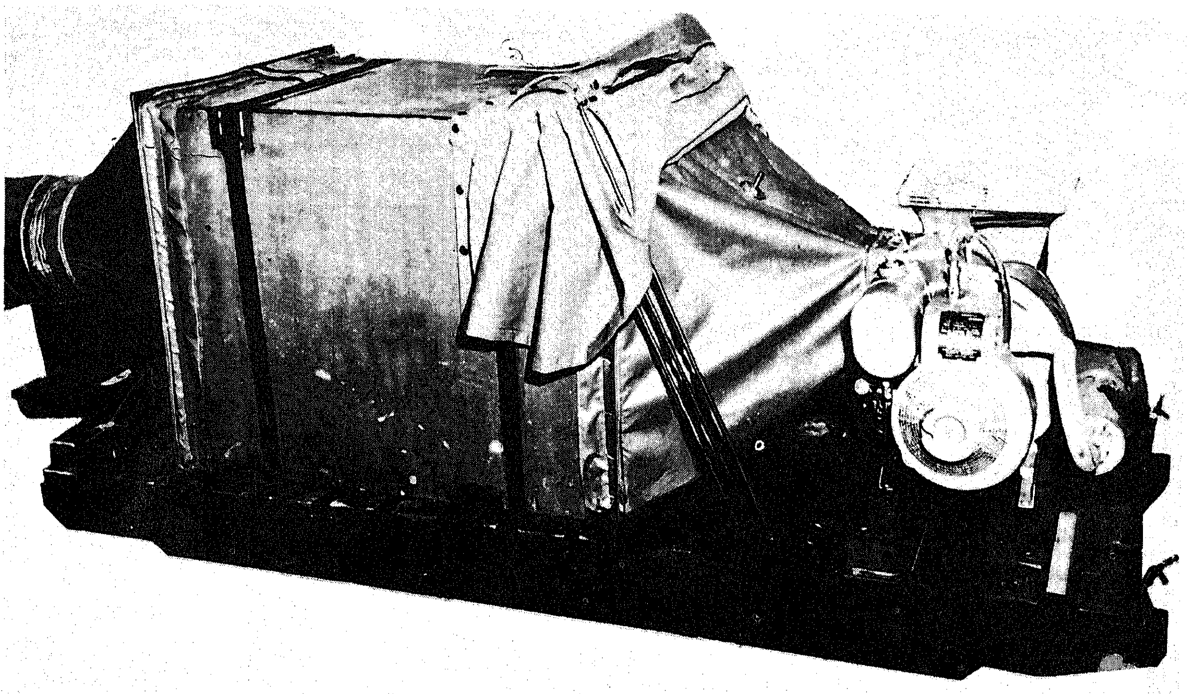


Figure 84. M9 gas-particulate filter unit.

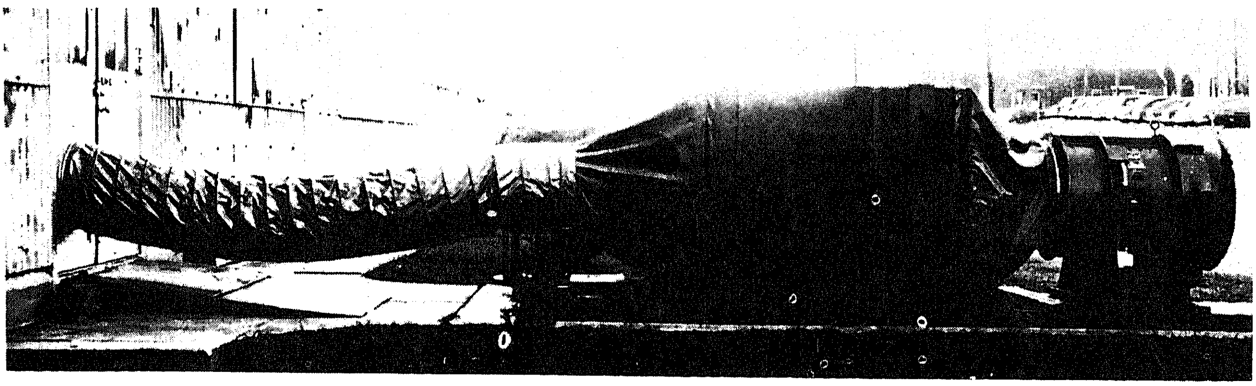


Figure 85. M12 gas-particulate filter unit.

unit should extend above ground level to provide air from an upper stratum in which there is less likelihood of agent concentration than there is in air that clings to the ground surface. The intake should be designed so that condensates and other liquids can be drained at a lower point in the system to prevent the liquid from reaching the filter elements. Iron or steel pipe is desirable for constructing an inlet system. A 4-inch diameter pipe is the smallest recommended for general usage.

88. Airlocks

An entry airlock system is necessary to the ventilated shelter if entry or departure is to be made without total loss of internal pressure. An

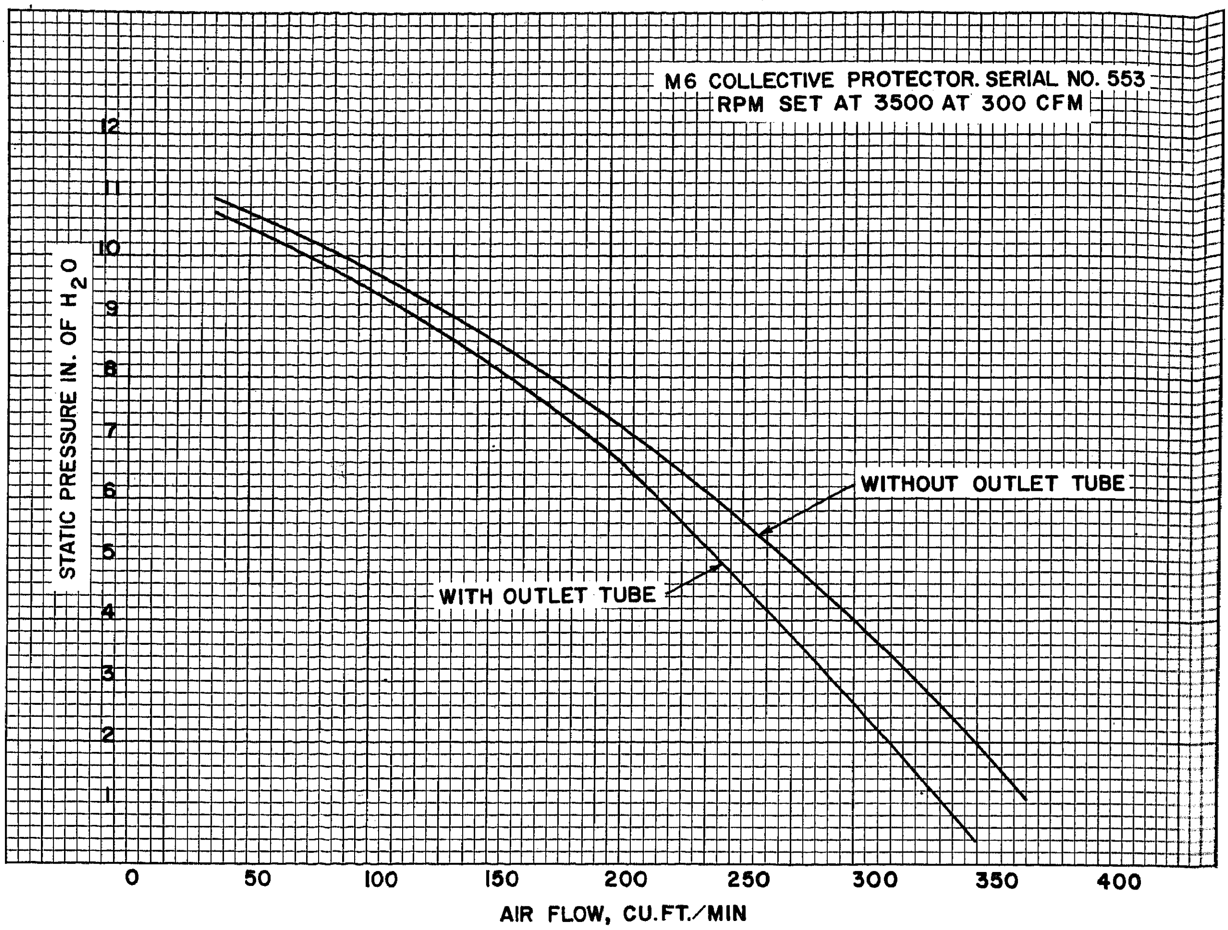


Figure 86. Performance characteristics, ABC–M6 gas-particulate filter unit, 300 cfm.

airlock is an intermediate chamber between the inside and outside of a shelter maintained at a pressure less than that of the main shelter but greater than atmospheric pressure. The system can be developed as a double airlock, providing two chambers and three doors, or a single airlock with one chamber and two doors. The overpressure in the outermost chamber should be maintained at approximately 0.3-inch water with inner chambers or inclosures progressing higher in pressure in increments of about 0.1-inch water. No standard dimensions for an airlock chamber have been established. The only requirement is that it be of sufficient size to enable passage of an individual with enough freedom to shut each door behind him before opening the next, and allowing him to perform such a limited amount of personnel decontamination as may be necessary.

89. Pressure Control Devices

Because it is necessary to insure an outward flow of air from the shelter at all times, several devices have been developed to insure this. An antibackdraft valve is used on the outermost wall of the pressurized inclosure system to enable outward passage of air while preventing any outside overpressure from creating a contaminated blowback into the shelter. Air pressure regulators are used to insure proper flow of air through the airlocks or in any other place where airflow regulation may be required. Air deflectors are installed on the effluent sides of the regulator to create turbulence in the passing stream, thus creating a scavenging process to force out any possible contamination.

a. The AN-M1 antibackdraft valve (fig. 91) consists of an 8-inch square duck with a valve

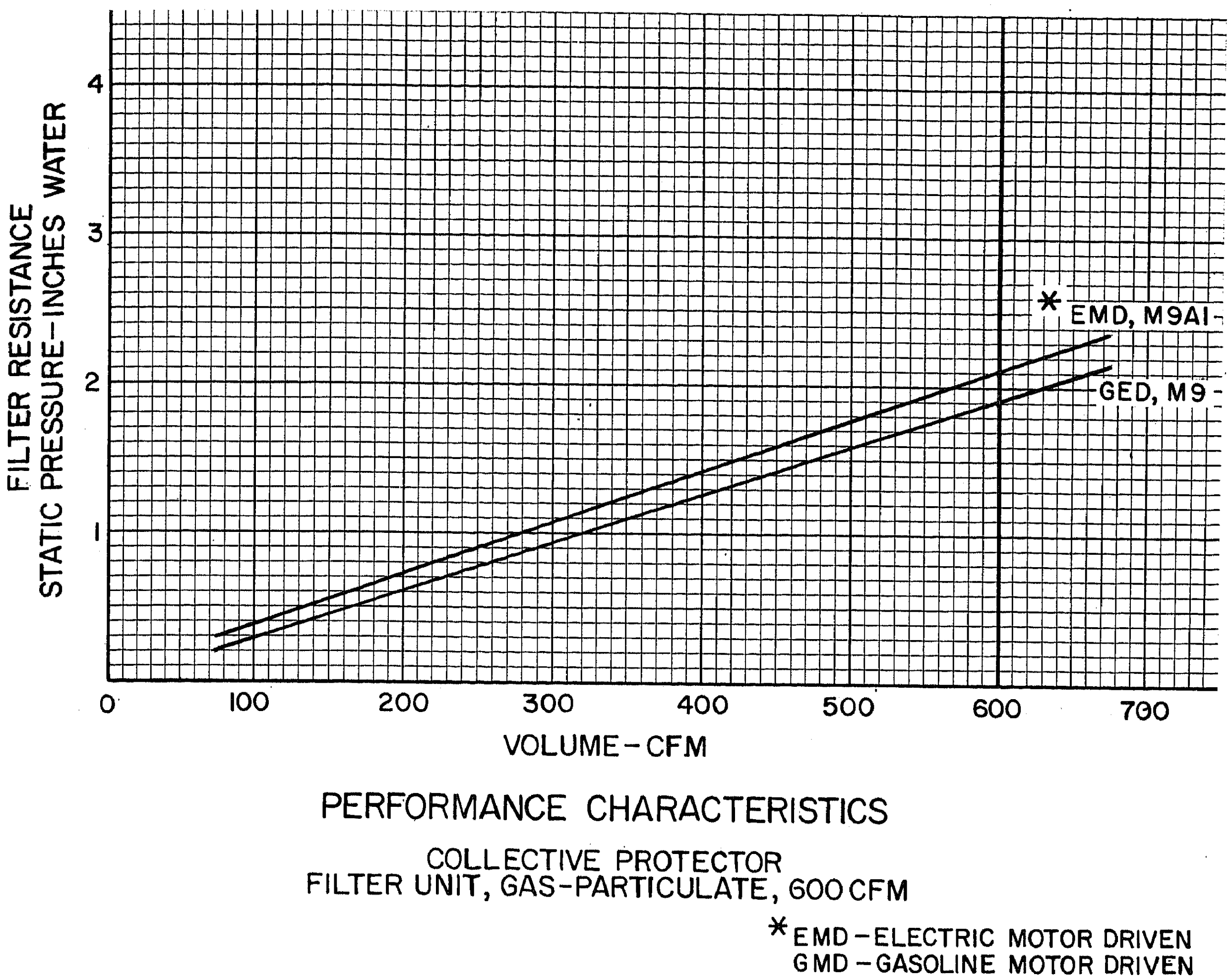


Figure 87. Performance characteristics, gas-particulate filter unit, 600 cfm.

flap resting at an angle of 20° to the vertical. A rod extending back into the opening is provided with a counterweight and locknut. When the weight is screwed to various positions, the amount of force required to swing open the valve flap varies; thus the pressure within the shelter can be regulated.

b. The M2 antibackdraft valve (fig. 92) not only controls the pressure within the shelter and prevents a reverse flow, but also measures the rate of airflow through the shelter. It consists of an 11- by 16-inch rectangular duct with a flap resting vertically when closed. The position by a counterweight on the shaft determines the amount of opposition which the valve offers to the flow of air, thereby controlling the pressure. A pointer located on the inside of the valve indicates the angular degree of opening of the cover. The amount of opening can then be converted into rate of airflow by using a graph (fig. 93) on which the position of the counterweight is plotted against the position of the cover for various rates of airflow. Thus, if the counterweight is located 2 inches from the edge of the arm and if the angle of opening registers 9° on the scale, intersection of these coordinates is found to pass through the 275-cfm (7.7 cu m/min) curve. Therefore, the rate of airflow is 275 cfm (7.7 cu m/min).

c. The M1 air pressure regulator (fig. 94) is essentially a device consisting of a 13- by 23-inch steel frame supporting a sliding panel

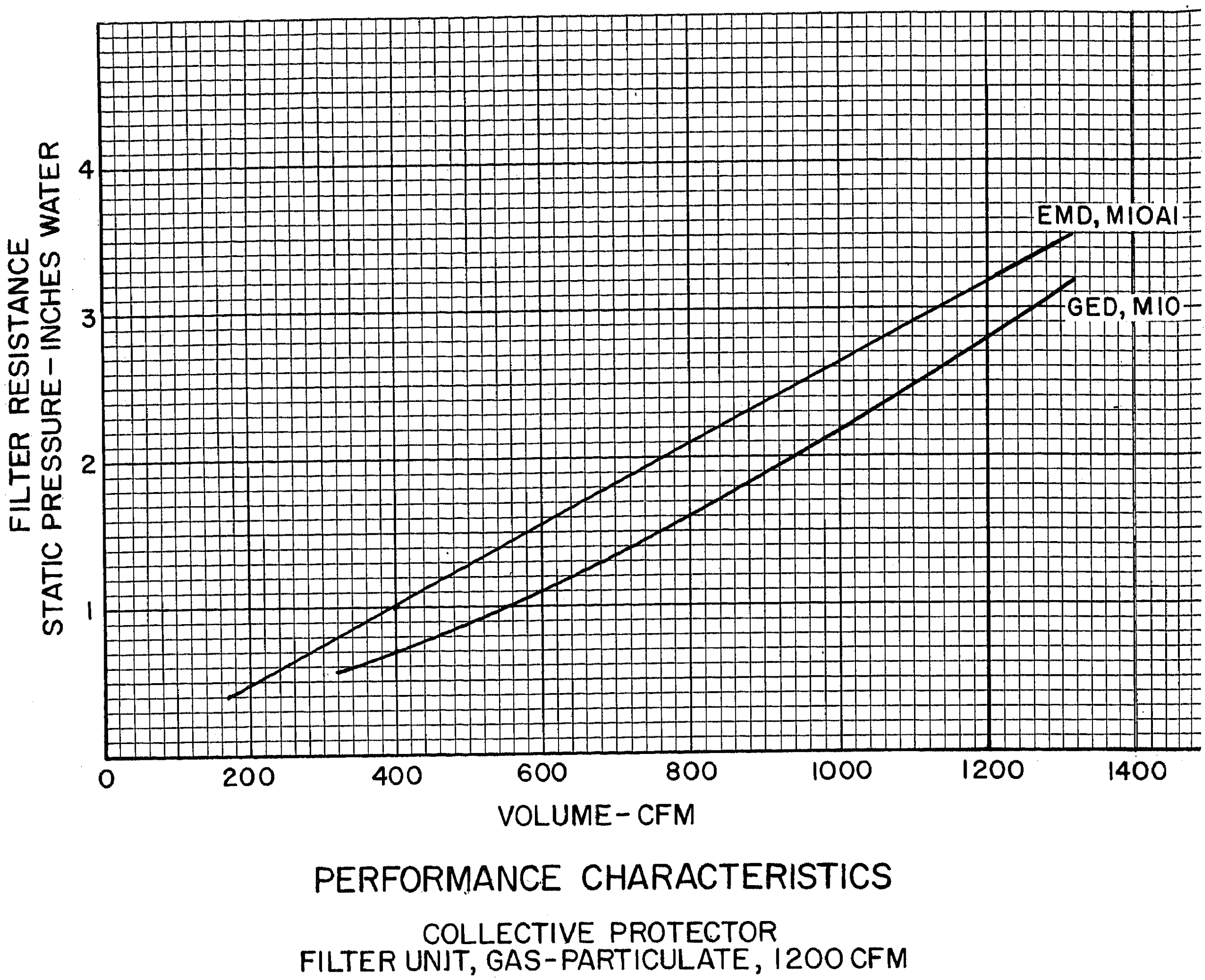


Figure 88. Performance characteristics, gas-particulate filter unit, 1,200 cfm.

which permits changing the size of a 9- by 9-inch opening. The frame is bolted to an opening in the wall between airlocks or sections of the shelter and is cushioned with a pressed felt pad. The air deflector is a component of the regulator and is bolted to the outer side of the regulator to reduce the possibility of creating stagnant air points in the chambers. Figure 95 shows a simple arrangement of the necessary equipment in a ventilated shelter providing CB protection.

d. Although not essential to the protection requirement, a locally improvised manometer will assist in maintaining suitable air pressure through the shelter. The instrument, if utilized, should be designed to read a static pressure of 2 inches of water. A draft gage, reading in increments of one one-hundredth of an inch, is most suitable. A manifold panel should be included, with connections to all chambers of the shelter and one to the outside to act as a base. For simpler operation, a U-tube manometer can achieve fair results.

e. To prevent blowout of the filter elements from sudden and extreme overpressures, an M1 antiblast closure (fig. 96) is installed on the air inlet line to the filter unit. The device permits passage of 300 cfm (8.5 cu m/min). If a greater inlet rate is necessary, additional closures must be added in parallel. The closure(s) should be mounted vertically. When a sudden overpressure occurs, a disk between two cast steel sections closes, preventing further passage of the blast wave. Perform-

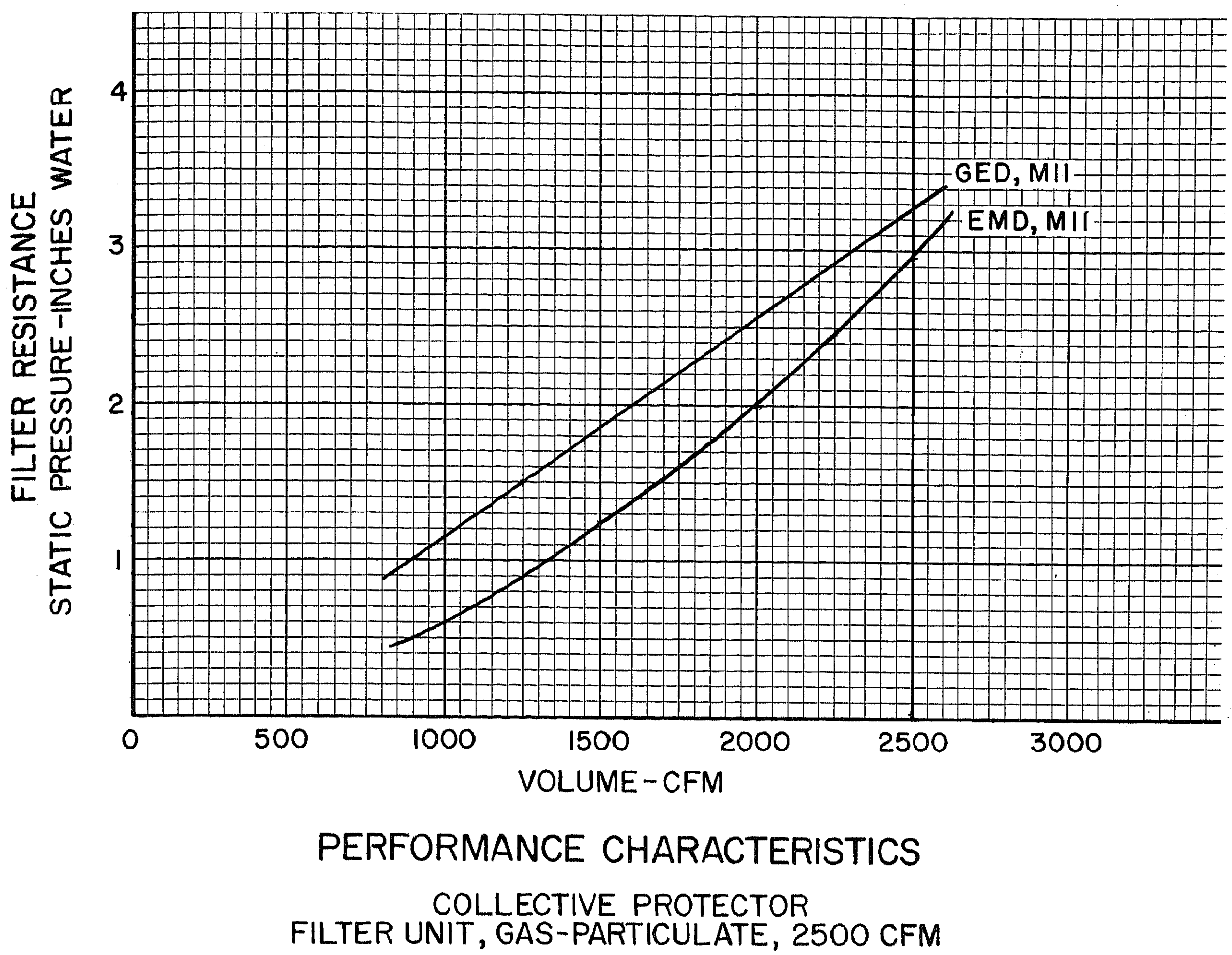


Figure 89. Performance characteristics, gas-particulate filter unit, 2,500 cfm.

ance characteristics for the antiblast closure are shown in figure 97. Because it is a mechanical device and a time lapse will occur before complete sealing of the disk, a surge tank between the closure and the filter must be included to prevent damage by that portion of the wave which succeeded in passing through. Experience has shown that pressures in excess of 100 psi (7 kg/sq cm) are unlikely to pass through the closure. Also, it has been determined that a surge volume of 5 cu ft (0.15 cu m) will reduce each 20 psi (1.4 kg/sq cm) overpressure to a safe level. Therefore, a surge volume of 25 cu ft (0.75 cu m) will adequately prevent rupture of the filters. The tank should be of 16 gage steel minimum; any shape will suffice. If, however, the filter is inclosed in a protected volume of suitable surge size, then this volume can act as the receptacle for the initial overpressure, and the need for a specific tank will be eliminated. If the entire shelter or a specific area of the shelter is also designed against blast, a similar arrangement should be established on the effluent side of the final air regulator device to be included.

90. Decontamination of Entering Personnel

The extent of decontamination of personnel entering the ventilated shelter from a toxic environment will vary, depending upon the degree of individual contamination. The primary concern is that of maintaining a safe community atmosphere.

a. When complete decontamination facilities cannot be included, reliance must be placed on the individual protection and treatment set. If, under such conditions, however, individuals are

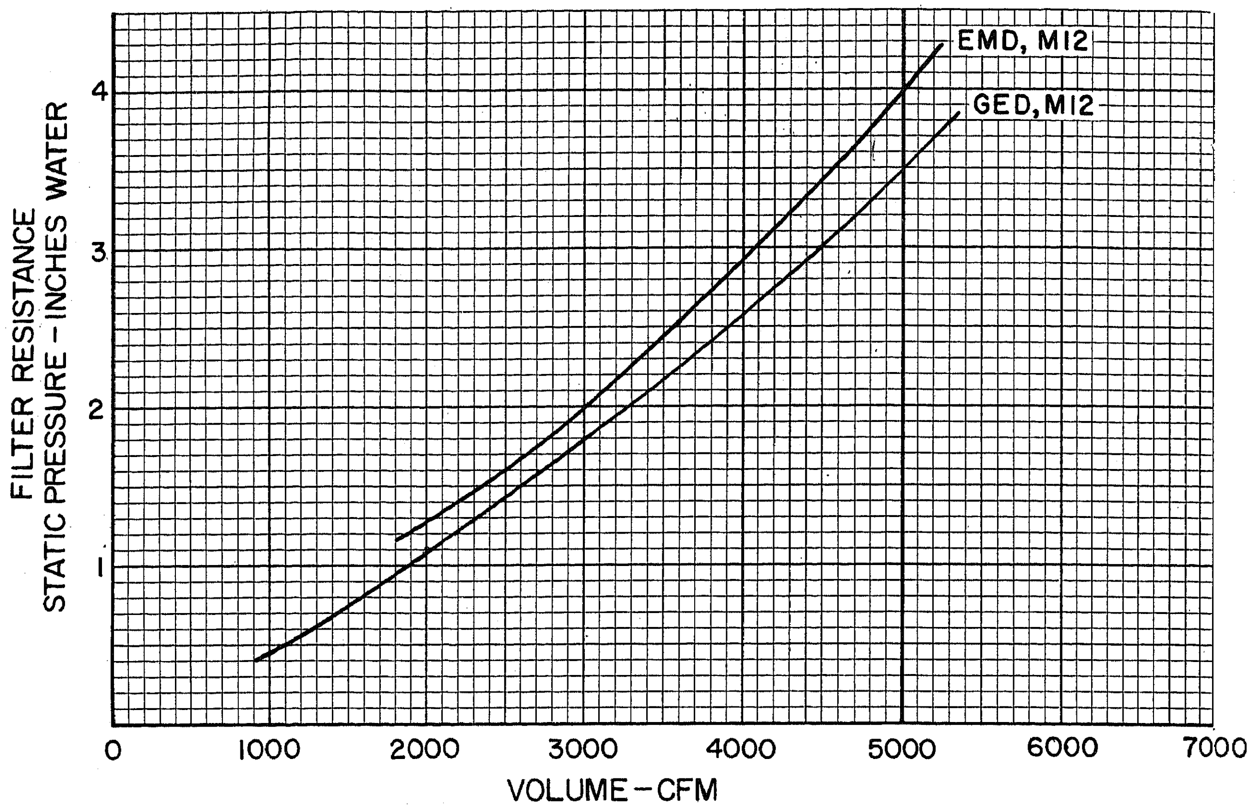


Figure 90. Performance characteristics, gas-particulate filter unit, 5,000 cfm.

contaminated to such a high level that the community atmosphere would be endangered, they should be sent to an aid station for additional treatment rather than be given entrance. For the most part, decontamination should be accomplished in the airlocks so that any toxic agents entering the atmosphere because of the process will be scavenged from the shelter complex by the outward flow of air.

b. For the most complete treatment, entering personnel should remove individual equipment (other than the protective mask) and boots outside the airlocks. In a double airlock system, outer garments should be opened or unbuttoned in the first lock and discarded in the second. (Both operations would be done together in a single lock system.) The airlock should be provided with suitable sealed containers for contaminated garments or with contaminated clothing chutes. The M1 contaminated clothing chute (fig. 98) provides a means to remove the clothing from the airlock to an outer area without personnel or lock becoming more contaminated in so doing. Inside the airlocks, a decontamination room should be established in which individuals could complete any necessary decontamination. If facilities for showering can be incorporated into the shelter, final decontamination by flushing and washing should take place. For estimation, it can be assumed that about 9 gallons (34 liters) of water (3 gallons (11.25 liters) for 3 minutes) will be needed per individual to insure adequate flushing and removal of any agent. An ideal situation and

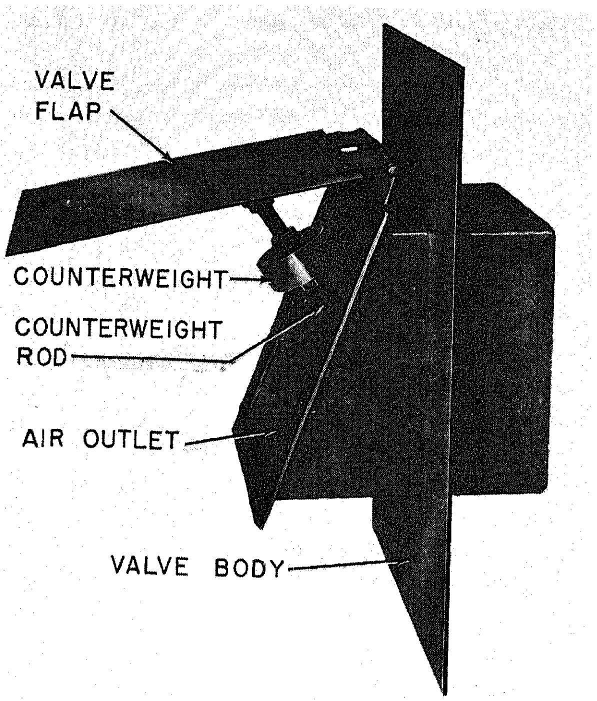


Figure 91. AN–M1 antibackdraft valve.

design for the decontamination process can be obtained by reference to TM 3–220. An accessory item to the protective shelter to help prohibit passage of contamination from the decontamination room to the main shelter is the ABC-M1 permeable membrane door (fig. 99) which is designed for use in a 3- by 7-foot passage. The door furnishes a means of passage for personnel by allowing the individual to wedge himself between twin sections of the door. A continuous flow of air passes through the fabric of the door preventing contamination from entering further. Using the wedge technique, the individual creates the minimum opening necessary for passage, thereby reducing the change of contamination spreading. The permeable membrane door can be used only as an inner door in the shelter. When not in use, the two sections can be folded out of the way.

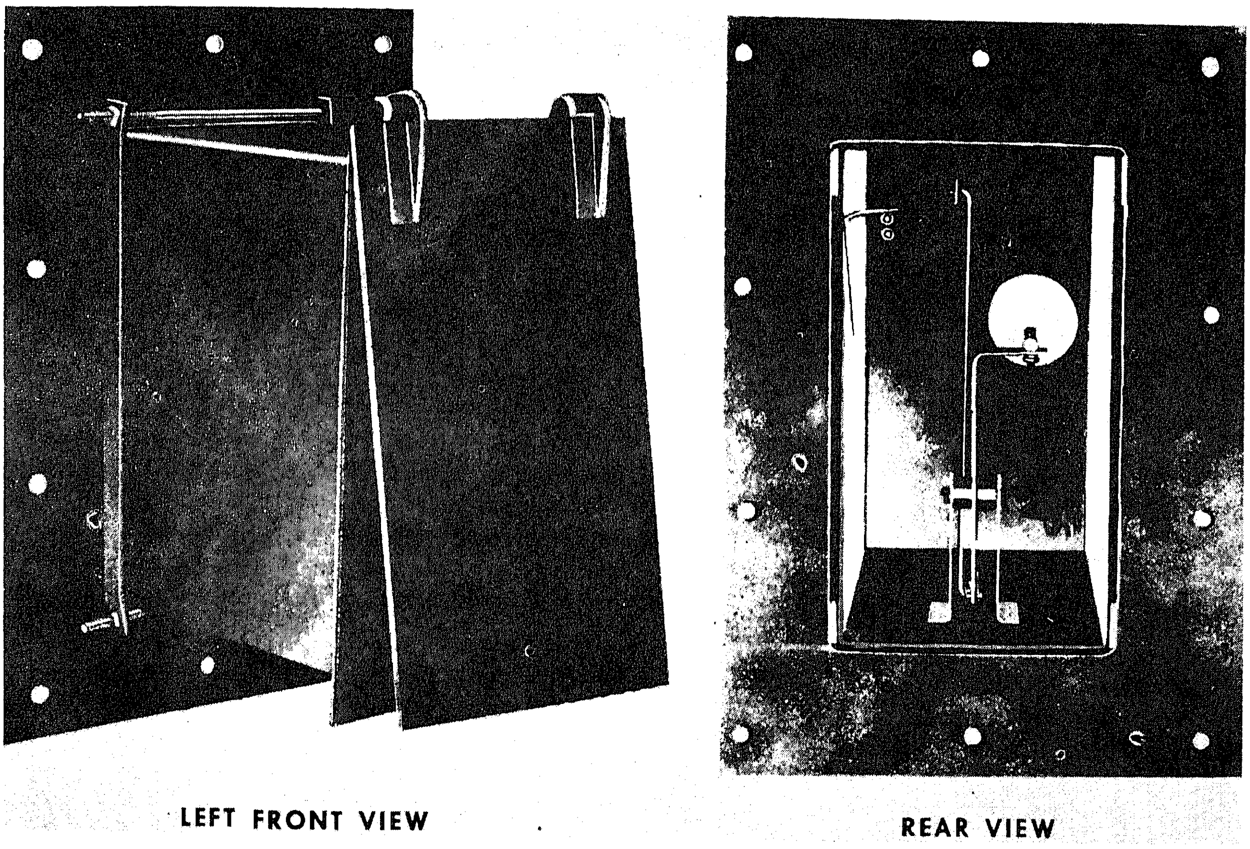


Figure 92. M2 antibackdraft valve.

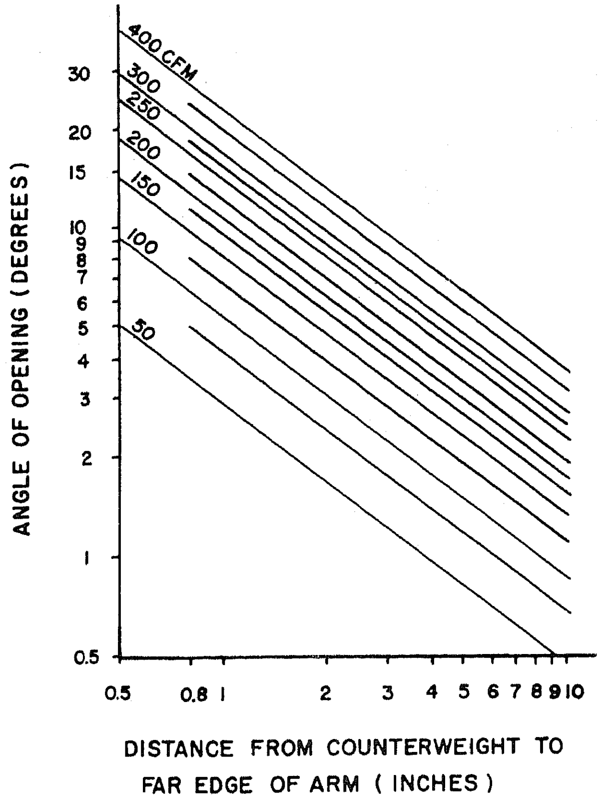


Figure 93. Airflow curves for the M2 antibackdraft valve.

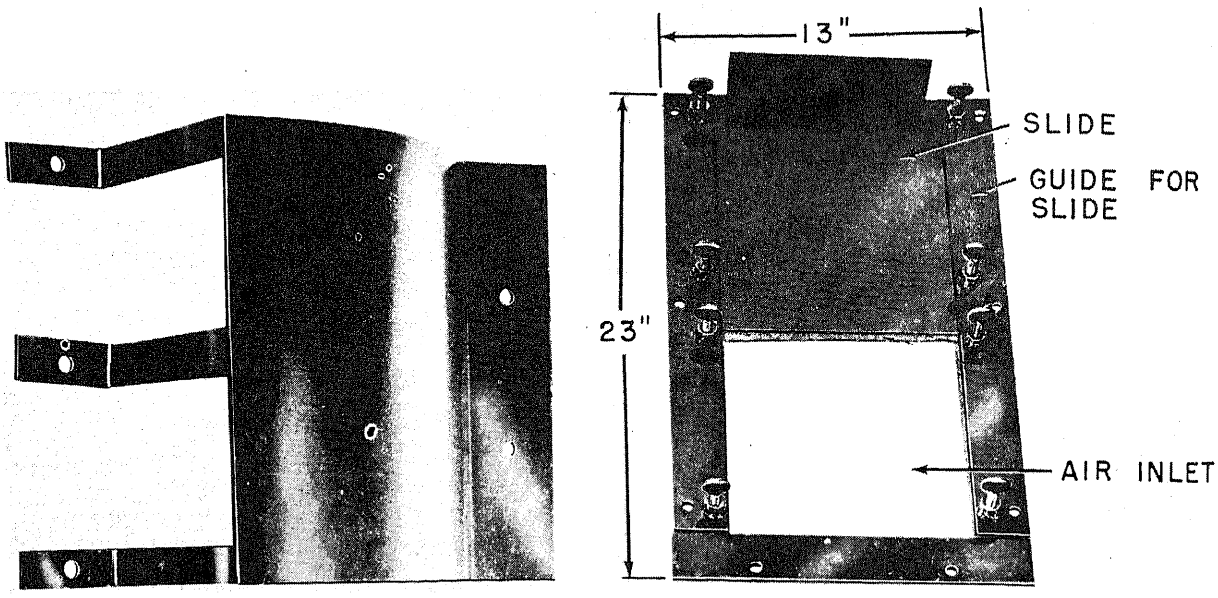


Figure 94. M1 air-pressure regulator with deflector.

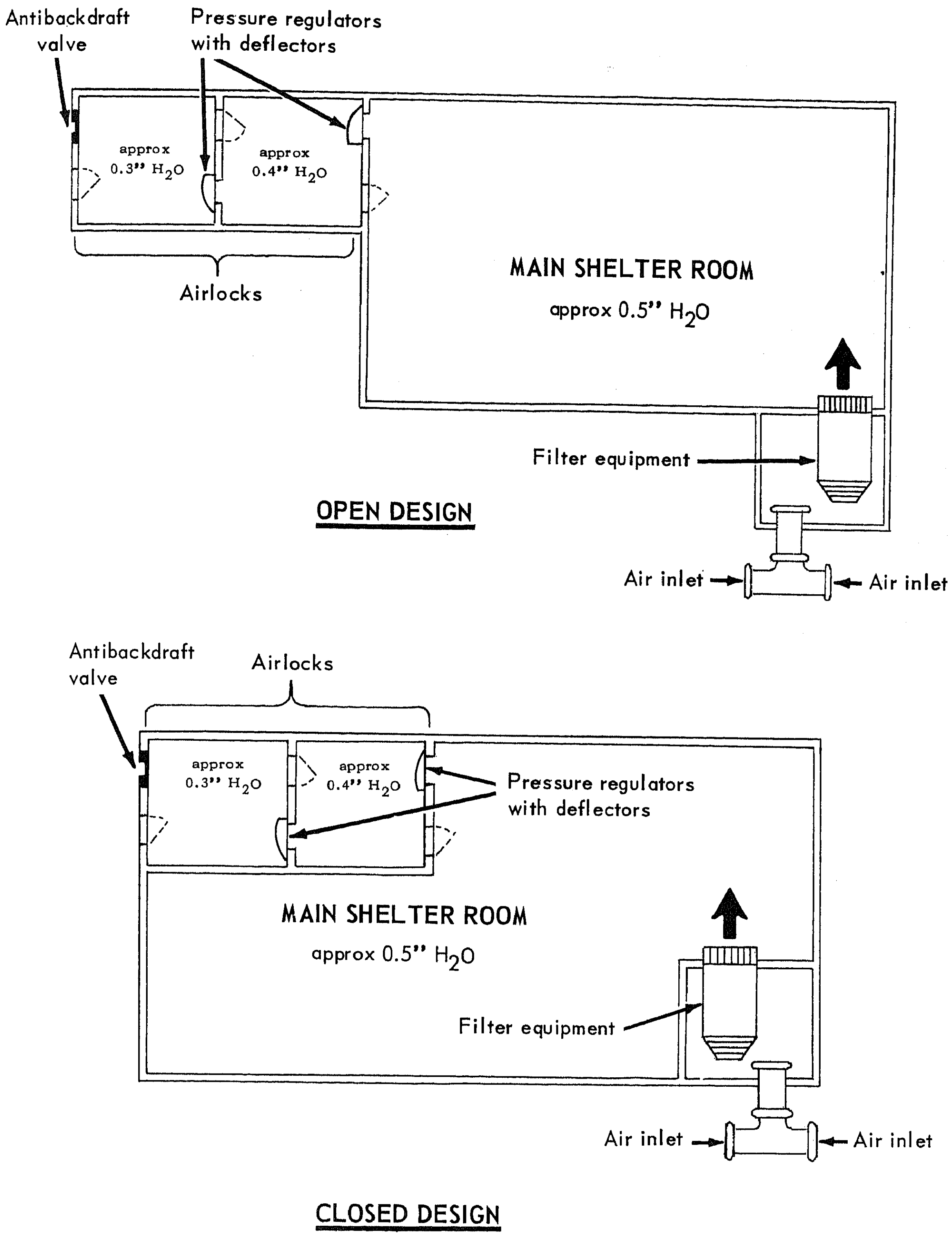


Figure 95. Overall design for a ventilated shelter providing CB protection.

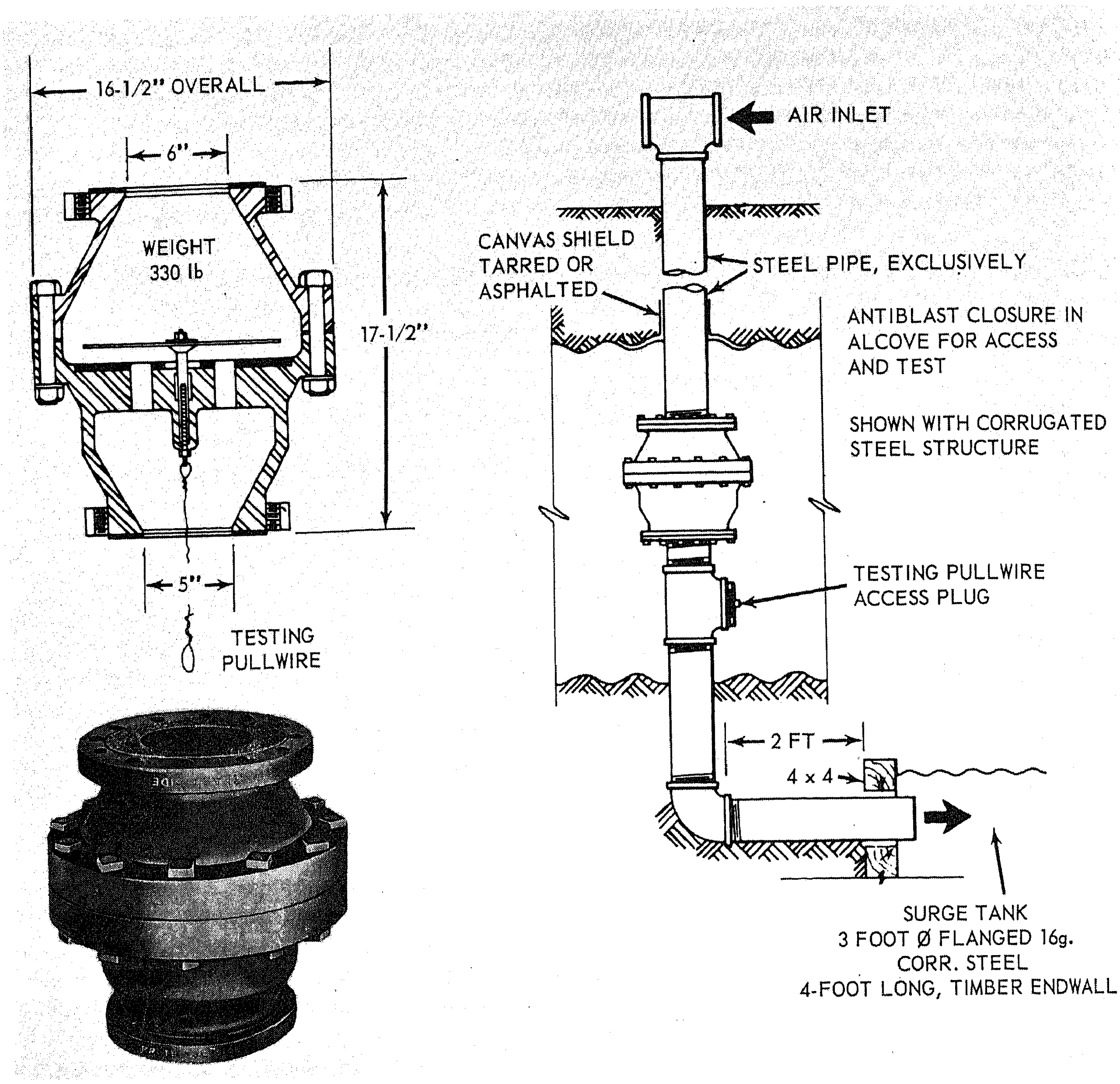


Figure 96. M1 antiblast closure.

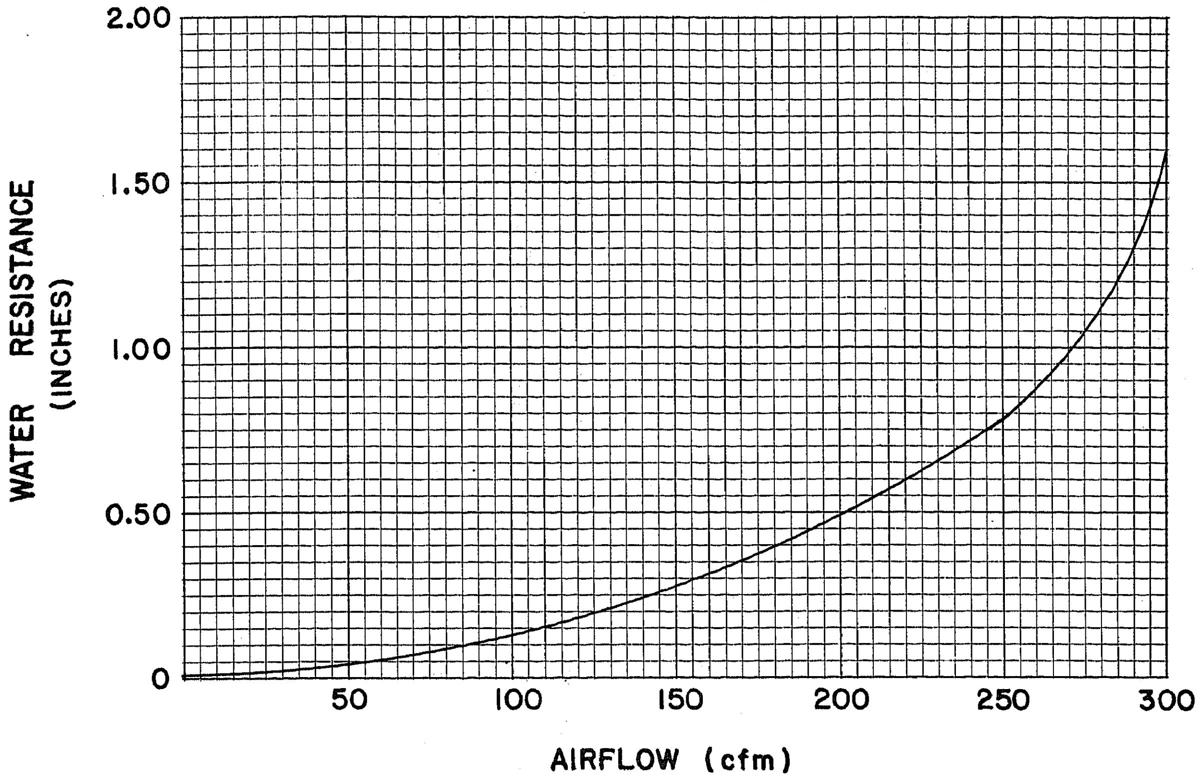


Figure 97. Performance characteristics, M1 antiblast closure.

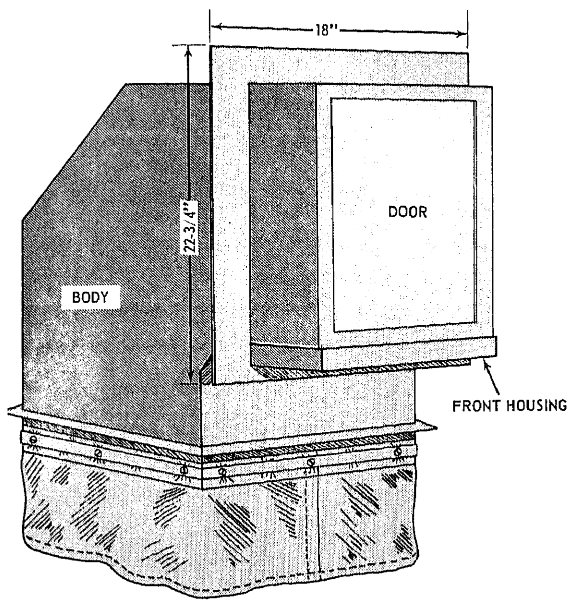


Figure 98. M1 contaminated clothing chute.

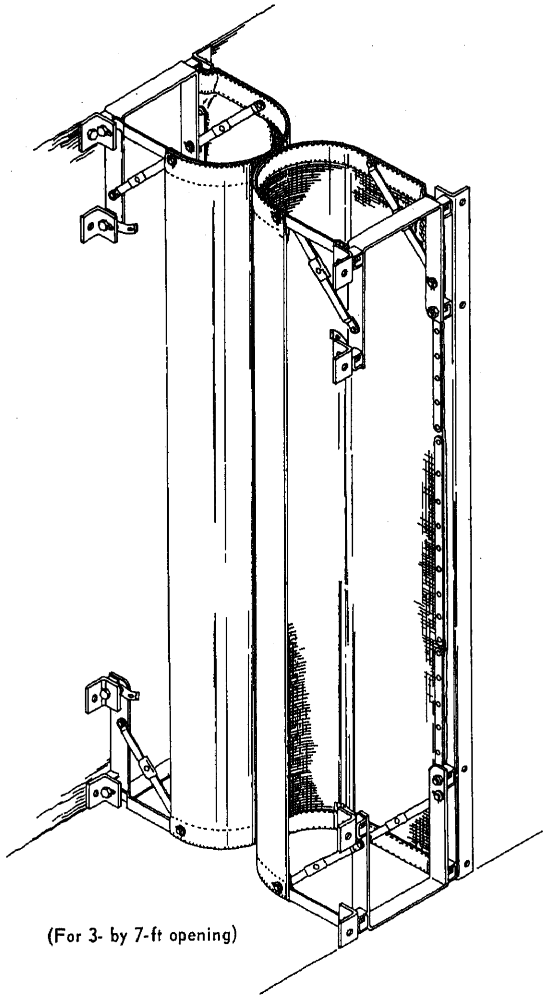


Figure 99. ABC–M1 permeable membrane door.

CHAPTER 5

ENVIRONMENTAL ENGINEERING

Section I. INTRODUCTION

91. Habitable Shelters

No structure is a worthy shelter unless it is habitable during the required period of occupancy. It has been found that a rather elaborate mechanical system of life support is required to maintain the chemical and thermal characteristics that make a shelter fit for human occupancy over an extended period. Human occupany of a confined space produces at least five important alterations in the properties of the air:

The chemical environment	*a* The carbon dioxide content is increased. *b* The oxygen content is decreased. *c* Products of decomposition, accompanied by odors, are given off.
The thermal environment	*d* The temperature increases. *e* The humidity is increased by the evaporation of moisture from the skin and lungs.

92. The Chemical Environment

a. Air Vitiation.

(1) The normal air components of primary concern in shelters are oxygen, carbon dioxide, and water vapor. Some degree of control must be provided for these components in shelters or in any other occupied space. Appropriate measures must be considered and taken to protect against the hazards of radioactive fallout particles and other airborne toxic, noxious, or pathogenic contaminants such as carbon monoxide, hydrocarbon vapors, odorous substances, and chemical or biological agents.

(2) An approximate relationship between physical activity, energy expenditure, oxygen consumption, carbon dioxide production, and rate of breathing is shown in table XIX with reference to the "average" man.

Table XIX. Energy Expenditure, Oxygen Consumption, Carbon Dioxide Production, and Rate Of Breathing in Man

Physical activity	Energy expenditure		Oxygen consumption		Carbon dioxide production		Rate of breathing	
	BTU/hr	Cal/hr	Cu ft/hr	Cu m/hr	Cu ft/hr	Cu m/hr	Cu ft/hr	Cu m/hr
Prone, at rest	300	75,600	0.60	.017	0.50	.014	15	0.42
Seated, sedentary	400	100,800	0.80	.023	0.67	.019	20	0.57
Walking*	1,000	252,000	2.00	.057	1.67	.047	50	1.42
Heavy work	1,500–3,000	378,000–756,000	3.00	.085	2.50	.071	75	2.12

*Includes movement in normal course of duty by an office staff.

b. Austere Chemical Tolerance Limits.

(1) Oxygen depletion and carbon dioxide buildup are of little concern in properly ventilated shelters, but they are important considerations in poorly ventilated, unventilated, or scaled shelters. Oxygen concentrations below 16 percent and carbon dioxide concentrations above 1.5 percent by volume are objectionable for long durations. Distress due to these factors would be increased if the abnormal conditions occurred simultaneously or if the time of exposure were prolonged. Oxygen concentrations below 10 percent and carbon dioxide concentrations above 5 percent may be acutely dangerous. These concentrations, occurring in a short duration (hours). are used as the extreme emergency tolerance limits. An individual will note a slight effort in breathing with CO_2 concentrations in excess of 3 percent. A limiting concentration of carbon dioxide will develop before oxygen is depleted to a correspondingly restrictive level, that is, unless means are used to absorb carbon dioxide without replacing oxygen. For prolonged occupancy, the intake of fresh air should be enough to maintain a carbon dioxide concentration of less than 1 percent by volume.

(2) Figure 100 shows the relationship between the concentration of carbon dioxide and oxygen in occupied spaces, the rate of ventilation per person, the volume of space per person, and the time of entry into a closed shelter. This chart is based on an oxygen consumption of 0.90 cu ft (0.025 cu m) hr/person and a carbon dioxide emission of 0.75 cu ft (0.021 cu m) hr/person, which would be representative of people in confined quarters. The example shown by dotted lines indicates that a carbon dioxide concentration of 3.50 percent by volume will develop in 10 hours in an unventilated shelter having a net volume of 235 cu ft (6.6 cu m) person and that the oxygen content of the air will then be 16.25 percent by volume.

c. Sustaining Control of the Chemical Environment.

(1) *Air ventilation.* Ventilation with pure outside air is the most economical method for maintaining the necessary chemical quality of air in a shelter. The recommended minimum ventilating rate of 3 cfm (0.08 cu m/min) per person of fresh air will maintain a carbon dioxide concentration of about 0.50 percent by volume in a shelter occupied by sedentary people. However, it should be noted here that an air replacement rate of 3 cfm (0.08 cu m/min) per person is not in itself sufficient to control the thermal tolerance limits within the shelter (paras 93–96). For normal operating conditions (nonemergency) 10 cfm (0.28 cu m/min) per person is recommended.

(2) *Advantages of maintaining chemical control.* A capability for maintaining a conservatively low concentration of carbon dioxide and a correspondingly safe concentration of oxygen in a shelter has a number of advantages, including the following:

(*a*) The shelter may be occupied longer after shutdown of a ventilating system because of fire or for repair of disabled equipment.

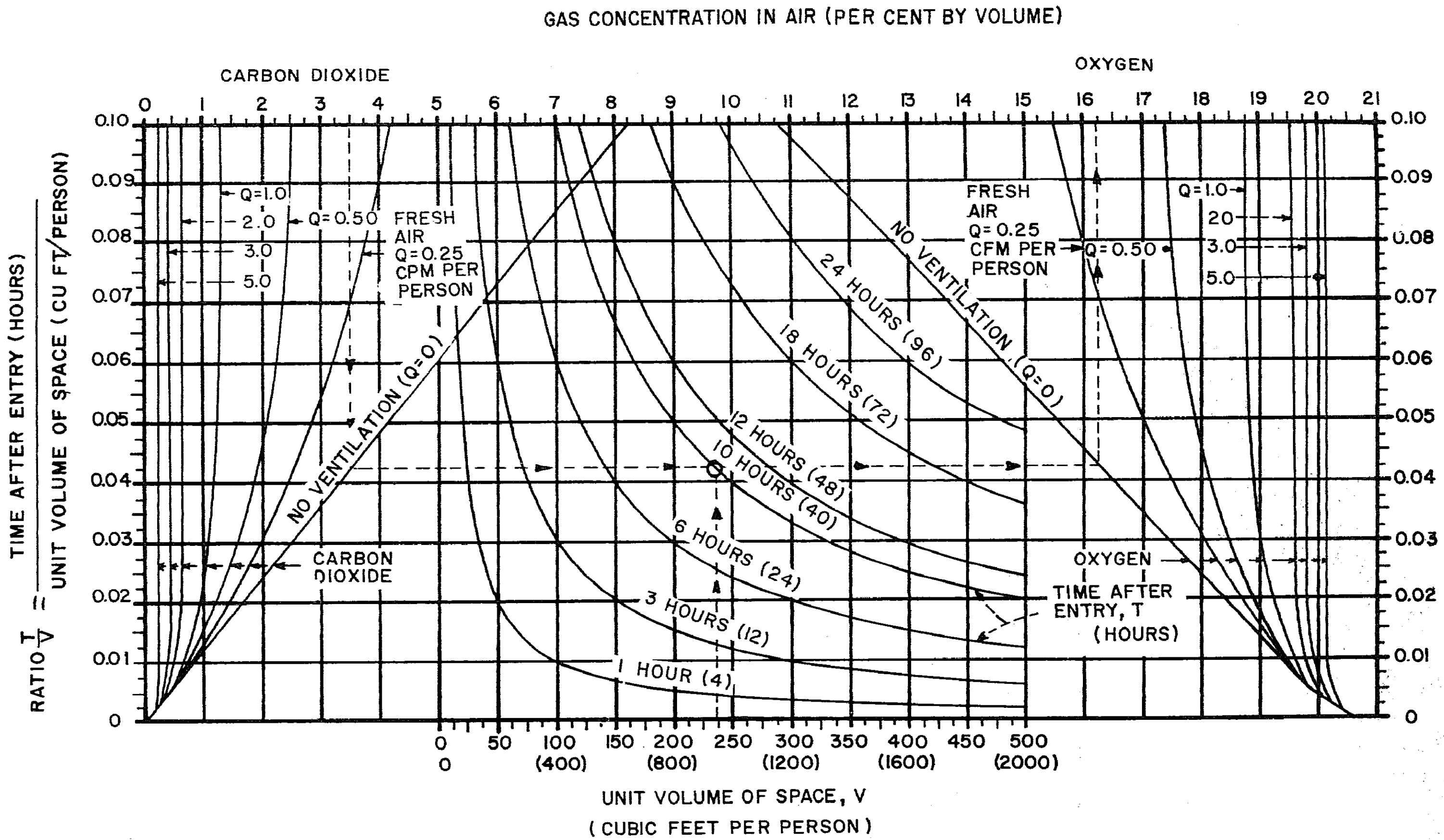
(*b*) Intermittent operation of a manual blower may become practicable.

(*c*) Greater physical activity in the shelter becomes permissible.

(*d*) Environmental conditions with respect to temperature, humidity, moisture condensation, air distribution, air motion, and odors, as well as oxygen and carbon dioxide, may be improved without supplementary apparatus.

93. The Thermal Environment

a. Heat and Moisture Sources. Some of the internal heat and moisture sources in shelters



TERMINAL VALUES OF GAS CONCENTRATION

RATE OF VENTILATION (CMF/PERSON)	TERMINAL CONCENTRATION (PERCENT BY VOLUME) CARBON DIOXIDE	OXYGEN
0.25	5.35	14.13
0.50	2.67	17.23
1.00	1.35	18 77
2.00	0.69	19.53
3.00	0.47	19.79
5.00	0.29	20.11

FRESH AIR QUANTITIES CORRECTED TO STANDARD DENSITY OF 0.075 LB CU FT

PHYSICAL DATA

OXYGEN CONSUMED = 0.90 CU. FT/HR/PERSON
CARBON DIOXIDE PRODUCED = 0.75 CU. FT/HR/PERSON
MOISTURE LOSS FROM BODY = 0.144 LB/HR/PERSON
OXYGEN IN FRESH AIR = 20.62 % BY VOLUME
CARB DIOXIDE IN FRESH AIR = 0.03 % BY VOLUME
DRY-BULB TEMPERATURE = 77° F = 25°C
RELATIVE HUMIDITY OF FRESH AIR = 50%
BAROMETRIC PRESSURE = 760 MM OF HG

REFERRED TO DENSITY AT 0°C, 760 MM OF HG

Figure 100. Carbon dioxide and oxygen in occupied spaces.

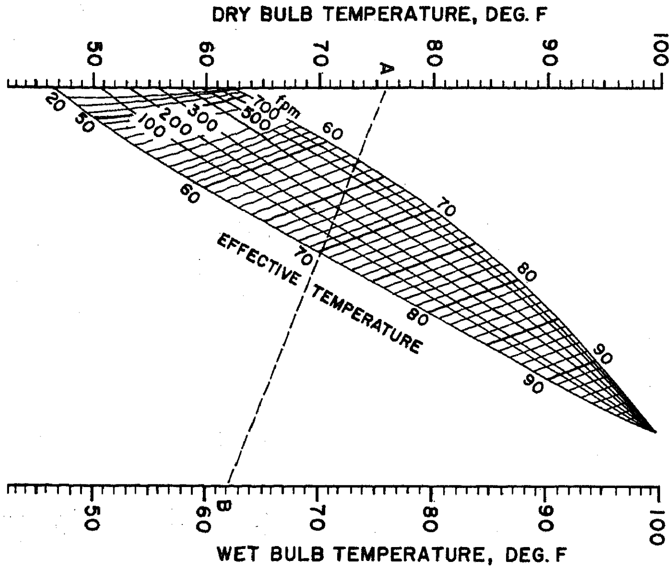


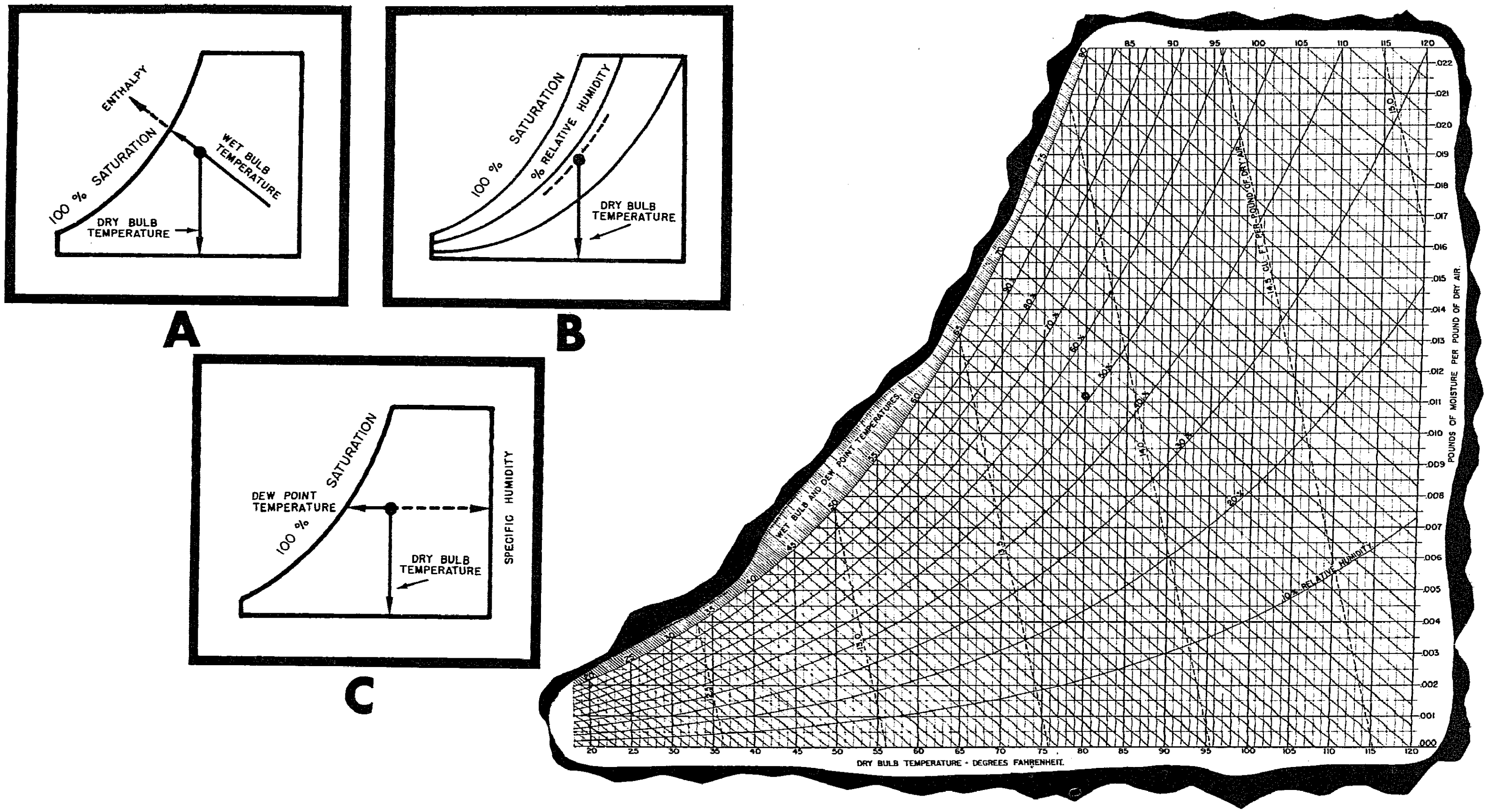
Figure 101. Effective temperature chart (for customary indoor clothing, light muscular work, and heating by warm air or radiators).

are the people themselves. Other sources are the lights, cooking appliances, radios and related equipment, motor-driven equipment, and the auxiliary power apparatus. Heat resulting from human metabolism must be almost continuously removed from the body. While the body can store heat temporarily, this produces a rise in body and skin temperatures and results in progressively increasing heat stress. Heat storage is necessary in a warm, humid environment when a state of equilibrium between the energy expended and the total heat loss cannot be attained at a normal body temperature. Activities to be expected in shelters would probably lead to per capita energy expenditures within the range of 300 to 1,000 Btu (75,600 to 252,000 cal) per hour with a mean of about 500 Btu (126,000 cal) per hour. However, under crisis conditions personnel should be as sedentary as possible and a figure of 400 Btu (100,800 cal) per hour per person is considered reasonable for calculations.

b. Austere Thermal Environment.

(1) An effective temperature of 85° F. (29.4° C) is about the maximum condition under which the energy expended by mildly active persons can be removed from the body without heat storage, and therefore is the recommended maximum inside design condition for shelters. The term *effective* temperature (ET) is defined as an index of the degree of warmth or cold felt by the human body in response to temperature, humidity, and air movement. A numerical value for various effective temperatures can be obtained from figures 101 and 102, by knowing the wet and dry bulb temperatures of the shelter air. It has been found that a relative humidity of 70 percent to 80 percent is usually present in densely occupied personnel shelters.

(2) The partition of total heat loss from the human body into sensible heat and latent heat is largely dependent upon the dry-bulb (DB) temperature of the environment. Sensible heat is that heat which when added to or subtracted from the air changes only its temperature, with no effect on the specific humidity. Latent heat effects a change of state without changing temperature, as in evaporating or condensing moisture. For a normal heat



DRY BULB TEMPERATURE . . . . . . The temperature indicated by a thermometer, not affected by the water vapor content of the air.

WET BULB TEMPERATURE . . . . . . The temperature of air indicated by a wet bulb thermometer; the temperature at which water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

DEW POINT TEMPERATURE . . . . . The temperature to which water vapor in air must be reduced to produce condensation of the moisture contained therein.

RELATIVE HUMIDITY . . . . The ratio of actual vapor pressure in the air to the vapor pressure of saturated air at the same dry bulb temperature.

SPECIFIC HUMIDITY . . . . The weight of water vapor per pound of dry air.

Figure 102. Psychrometric chart.

loss of 400 BTU (100,800 cal) per hour per person, table XX shows a probable proportion between the dry-bulb temperature, total heat loss, sensible heat, latent heat, and amount of water evaporated. The tabulated values are representative for a sedentary or mildly active adult wearing optimum clothing in thermal equilibrium with the rather humid environment of a ventilated shelter. At temperatures above 85° F. (29.4°C.), the quantities for moisture evaporated may not be attainable if the relative humidity is high, and the resultant deficiency to latent heat loss would then cause the body temperature to rise. The validity of the sensible heat losses at dry-bulb temperatures below 70° F. (21°C.) depends on adding appropriate layers of clothng to maintain normal skin temperatures. A person wearing inadequate clothing would react to a chilling effect as the environmental temperature falls below 70° F., and the attendant values of total and sensible heat losses would then be considerably higher than those shown in table XX. The quantities of water evaporated are related to austere rationing of drinking water in shelters.

Table XX. Relationship Between Air Temperature Heat Losses and Moisture Evaporated for Average Sedentary Man with Optimum Clothing

Dry-bulb temperature		Total heat loss		Sensible heat loss		Latent heat loss		Moisture evaporated	
°F.	°C.	BTU/hr	Cal/hr	BTU/hr	Cal/hr	BTU/hr	Cal/hr	Lb/hr	Gr/hr
40	4.4	400	100,800	350	88,200	50	12,600	0.048	21.77
45	7.2	400	100,800	350	88,200	50	12,600	0.048	21.77
50	10.0	400	100,800	350	88,200	50	12,600	0.048	21.77
55	12.8	400	100,800	350	88,200	50	12,600	0.048	21.77
60	15.5	400	100,800	345	86,940	55	13,860	0.053	24.04
65	18.3	400	100,800	335	84,440	65	16,380	0.062	28.12
70	21.1	400	100,800	320	80,640	80	20,160	0.077	34.92
75	23.9	400	100,800	300	75,600	100	25,200	0.096	43.54*
80	26.6	400	100,800	270	68,040	130	32,760	0.125	56.70
85	29.4	400	100,800	220	55,440	180	45,360	0.173	78.47
90	32.2	400	100,800	120	30,240	280	70,560	0.269	122.01**
95	35.0	400	100,800	20	5,040	380	95,760	0.365	165.56
100	37.7	400	100,800	—80	—20,160	480	120,960	0.461	209.11
105	40.5	400	100,800	—180	—45,360	580	146,160	0.557	252.65
110	43.3	400	100,800	—280	—70,560	680	171,360	0.653	296.20

*Optimum comfort
**Austere

c. Use of Psychrometric. From the known properties of air, its condition can be located on the chart in figure 102, and all remaining properties can then be found by reading the appropriate scale—

A illustrates a condition plotted at the intersection of its dry bulb and wet bulb (WB) temperatures. The dry bulb temperature is represented in this figure by the vertical lines with its scale across the bottom. The wet bulb temperature is read along the saturation line and is represented in this figure by the solid diagonal lines.

B represents a condition plotted at the intersection of its dry bulb temperature and relative humidity. Relative humidity is represented on the figure by the curved lines which are marked in percent relative humidity.

C illustrates a condition plotted at the intersection of its dry bulb and dew point temperatures. The dew point temperature is read along the saturation line at the intersection of the horizontal specific humidity line. The value of the specific humidity is read from the scales at the right in pounds of moisture per pound of dry air by selecting the appropriate scale.

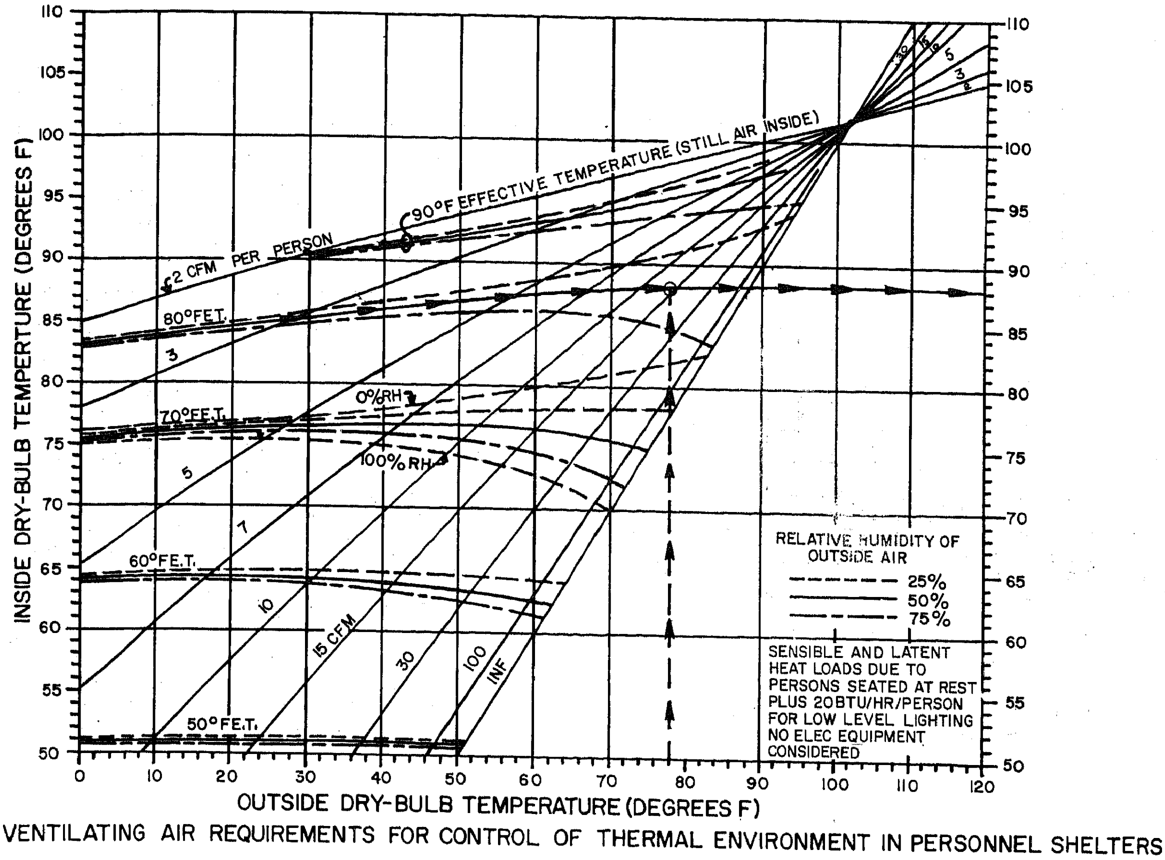


Figure 103. Ventilating air requirements for control of thermal environment in personnel shelters.

d. Control of the Thermal Environment. Three more or less distinct procedures may be used to control the thermal environment in a shelter—

(1) Cooling by forced or natural ventilation with outside air.

(2) Cooling by the effects of heat conduction into the surrounding earth.

(3) Mechanical cooling and dehumidifying with refrigeration or well water.

Various combinations may be used. In general, only method (3) provides positive and *reliable* control of temperature, humidity, and moisture condensation.

e. Cooling by Ventilation. The curves in figure 103 can be used to estimate the ventilating air requirements for control of environmental conditions in spaces occupied by personnel. On this chart various per capita rates of ventilation are plotted as a function of outside and inside dry-bulb temperatures and upon this background are superimposed the 50°, 60°, 70°, 80°, and 90° F. (10°, 15.5°, 21°, 26.6°, and 32.2° C.) still-air inside effective temperature curves for outside air relative humidities of 25, 50, and 75 percent. The 70° F. (21° C.) inside effective temperature curves for outside relative humidities of 0 and 100 percent are also shown. The heat and moisture loads upon which this chart is based consist of the sensible and latent heat emitted by a man seated at rest plus 20 BTU/hr/person (5040 Cal/hr/person) for low level lighting, that is, about 6 watts per person. Other internal heat loads and the transient cooling effect of earth conduction are not considered. The curves plotted in figure 104 are convenient data which show the quantities of outside air required at various dry-bulb tem-

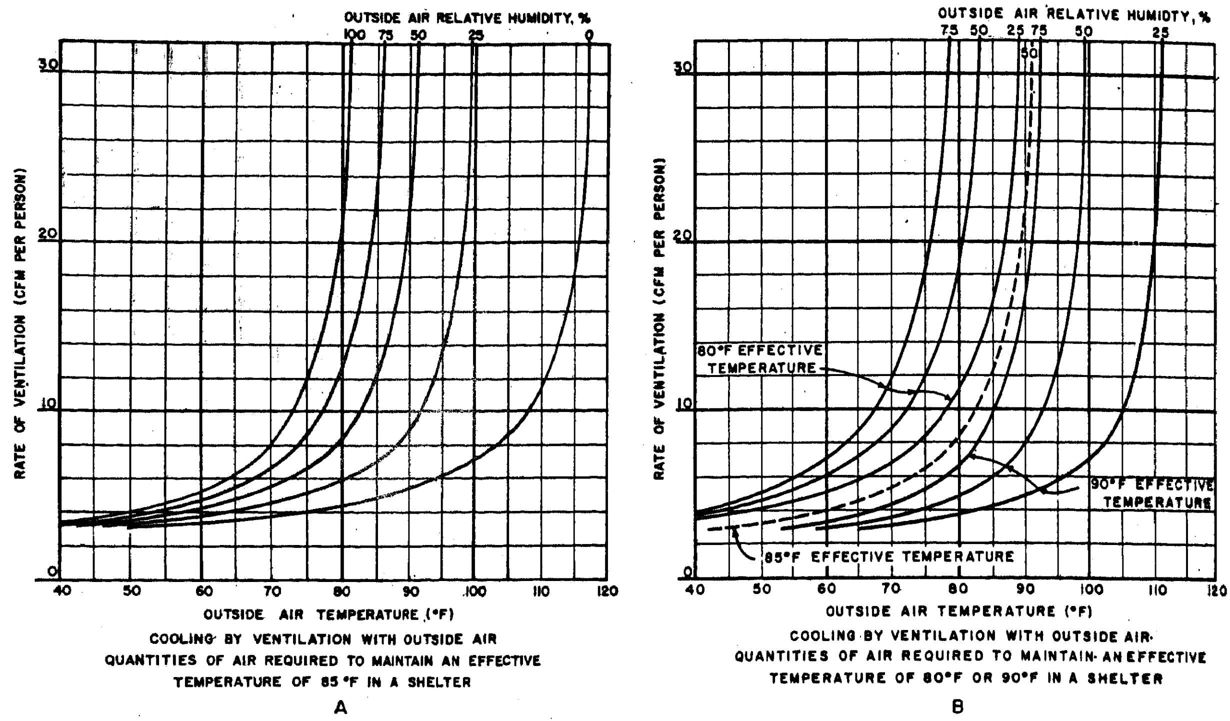


Figure 104. Cooling by ventilation with outside air.

peratures and relative humidities to maintain inside effective temperatures of 80° F., 85° F., and 90° F. (26.6° C., 29.4° C., and 32.2° C.) These curves graphically illustrate the limitations for adequate cooling by ventilation during hot, humid weather.

f. Effective Temperatures. The curves in figures 103 and 104 estimate the supply air quantity, temperature, and relative humidity necessary to maintain a given effective temperature in a shelter. For instance, an effective temperature of 80° F. (26.6° C.) can be maintained in a shelter with 15 cfm of air per person distributed at a dry-bulb temperature of 78° F. (25.5° C.) and 50 percent relative humidity. The dry-bulb temperature in the shelter wuold be 88° F. (31° C.)

g. Ventilated Air Requirements. If it is desired to consider the amount of ventilated air required for the removal of sensible heat caused by electrical and associated equipment, the following equation can be used:

$$Q = \frac{50\ H_s}{T - T_o}$$

Where Q = Volume of outside air entering shelter, cfm

$T-T_o$ = Temperature difference between inside and outside air, °F.

H_s = Sensible heat to be removed.

$\frac{\text{BTU}}{\text{Min}}$ specific heat of air is assumed to be $0.25 \frac{\text{BTU}}{\text{lb °F}}$ and the density of air is assumed to be $0.08 \frac{\text{lb}}{\text{cu ft}}$

Conversion factors:

$$1\ \text{KW} = 3412 \frac{\text{BTU}}{\text{hr}} = 57 \frac{\text{BTU}}{\text{min}}$$

$$1\ \text{HP} = 2545 \frac{\text{BTU}}{\text{hr}} = 42.5 \frac{\text{BTU}}{\text{min}}$$

h. Supplemental Cooling. An inspection of figures 103 and 104 leads to the conclusion that the recommended maximum effective temperature of 85° F. (29.4° C.) can be maintained in a personnel shelter at a ventilation rate of about 20 cfm (0.56 cu m/min) person for most localities. However, 85° F. (29.4° C.) effective temperature is nowhere near the comfort zone (70° to 75° F., or 21° to 24° C. DB with 50 percent relative humidity). It is readily seen that a 70° F. (21° C.) inside effective temperature with a 50 percent outside relative humidity cannot even be obtained when the outside temperature is over 74° F. (23.3° C.) Thus some type of supplemental cooling and dehumidification is required. It should be noted that if a high ventilation rate is used for cooling, then the following mechanical problems arise.

(1) Increased number of intake and exhaust ducts with overall increase in the vulnerability of the installation as larger egress areas are used.

(2) Increased number of blast valves required with the corresponding required surge area.

(3) Large volume filter units with a pronounced decrease in the load-up time for the filter units.

(4) Increase in the power demand with resulting increase in heat generation of the ventilating unit.

94. Space Requirements

An environmental factor of considerable importance is the *minimum* space and volume required for a person in a crowded shelter. The following can be used as design guides:

a. If no *mechanical* ventilation can be provided a net volume of 500 cu ft (14.16 cu m) per person may be used to determine shelter capacity.

b. If at least 3 cfm (0.08 cu m/min) of fresh air per person enters the shelter, each occupant should have 8 sq ft (0.74 sq m) of floor space and 60 cu ft (1.7 cu m) of volume.

c. For varying rates of ventilation, table XXI may be used.

Table XXI. Relation Of Space Requirements To Ventilation

Rate of air change (minutes)	Volume of space required per person	
	cu ft	cu m
1,000+	500	14.16
600	450	12.74
400	400	11.33
200	300	8.49
100	200	5.66
60	150	4.25
35	100	2.83
22	60	1.70

95. Earth Conduction Effects

A relatively cool soil or rock surrounding an underground shelter would absorb heat at a rate which is relatively high at first, but this high rate quickly diminishes with time as a temperature gradient is established in the adjacent material. The heat absorption is accompanied by a rise in temperature of the interior surfaces. This transient effect provides some supplementary cooling which tends to retard the rate at which the shelter temperature rises. However, this effect is small and should be neglected for the types of shelters discussed in this manual. If the temperature of the surrounding soil or rock is greater than of the shelter, it will add to the heat load of the cooling equipment.

96. Heating Devices

In cold climates some capability for heating is desirable to temper ventilating air or to avoid low or freezing temperatures when the shelter is not in use. Environmental temperatures of 50°F. (10°C.) or even lower, can be endured if winter clothing is available, the diet is adequate, and the people are in good health. Heat produced by the occupants will be effective in progressively warming the space, and this effect may be sufficient, particularly in underground shelters. Since the requirement for heat is relatively small, electrical resistance heaters are convenient and economical for this purpose. If an auxiliary power supply having a liquid-cooled engine is provided, waste heat can readily be used for both space heating and domestic hot water. Fuel burning appliances which take air for combustion from the occupied spaces and are not directly vented to the atmosphere may be hazardous and should be avoided.

Section II. DISASTER CONDITION AIR SUPPLY

97. Sealed-In Periods

a. Cutoffs.

(1) During an extreme emergency all ventilation may have to be cut off. *For example,* this might be necessary because of power failure, or the presence in the intake air of dangerous concentrations of carbon dioxide, carbon monoxide, or toxic combustion products. Experience in World War II showed that shelters located in built-up areas that are vulnerable to to mass fires should be capable of being closed off from the outside atmosphere for 24 hours. Other reasons for sealing would be for replacement or repair of machine parts. People isolated from a fresh air supply can survive for some hours on the volume of air within the shelter. The length of survival time depends on the volume of air available, the number of persons present, and their activity level. A sedentary person can be expected to consume 0.80 cubic feet (0.023 cu m) of oxygen per hour and exhale about 0.67 cubic feet (0.02 cu m) of carbon dioxide (table XIX).

(2) To make such cutoffs, an air shutoff valve should be installed in the intake and exhaust ducts.

b. Time Length.

(1) When a ventilating system is shut down, pressurization of the space is lost and the shelter must be well sealed to prevent the infiltration of contaminated outside air. Since the change in carbon dioxide concentration is the critical element in a closed environment, a safe allowable period can be determined from the volume of trapped air within the shelter. For example, the short-term allowable concentration of carbon dioxide is 5 percent and there is a space of 60 cubic feet (1.69 cu m) per person in the shelter. From figure 100 it can be computed that with no ventilation a 5 percent carbon dioxide concentration is reached in 4 hours. The same answer can be obtained by using the formula:

$$\text{SAP (hr)} = \frac{C_{sa} \times V}{F_{CO_2}}$$

Where: SAP = Safe allowable period, in hours

C_{sa} = Change in carbon dioxide concentration, expressed as a decimal. (The maximum short-term concentration allowable is 5 percent by volume.)

V = Shelter volume, in cubic feet

N = Number of persons occupying shelter

F_{CO_2} = Formative rate of carbon dioxide in cubic feet per hour per person. (See table XIX for rates.)

(2) The effective temperature may rise above 85° F. (29.4°C.) if the "cutoff" occurs when the shelter effective temperature is close to 85°F. (29.4°C.). This increase in effective temperature can be tolerated for periods of short duration.

(3) A rule-of-thumb to determine stay time without any ventilation is the following: In a sealed shelter, for every 10 cubic feet (0.3 cu m) of air per person, an individual can breathe 22 minutes before the CO_2 content rises to 3 percent and can breathe for about 41 minutes before the O_2 content drops to less than 14 percent.

98. Air Revitalization Materials

a. System of Air Revitalization. There are several closed environmental life support systems for prolonged periods without ventilation.

The following methods of air revitalization may be considered in order to prevent an untenable situation. These methods should not replace the conventional methods of ventilation and should not replace the conventional methods of ventilation and should be considered only as supplementary, for use in such cases as stoppage of the primary ventilation system. The chemicals used are classed in three types—

(1) Those which remove carbon dioxide from the air.

(2) Those which release oxygen into the air.

(3) Those which remove carbon dioxide and release oxygen simultaneously.

With the exception of the compressed oxygen tank method, all of the methods release considerable quantities of heat during the chemical reaction that takes place. This and the high cost may be detrimental factors in their usage, particularly in small shelters.

b. Absorb Carbon Dioxide.

(1) *Lithium hydroxide.* This is available in 21.6-pound (9.8-Kg) canisters. About 0.124 pound (56.24 gr) is required per man-hour to maintain a 3 percent carbon dioxide level. This chemical is used by adding water as prescribed on canister; one canister will last about 2 hours.

(2) *Cardoxide (soda lime).* This chemical can be obtained in bulk and placed in suitable canisters at the place of usage. About 0.34 pound (154.22 gr) is required per manhour to maintain a level of 3 percent carbon dioxide. It is activated by adding water.

(3) *Bara lime.* This is also obtainable in bulk. It can be placed on canisters. It is also water activated. About 0.5 pound is required per man-hour to maintain a 3 percent carbon dioxide level. Of the three materials herein discussed, this one is the least efficient in that it requires more storage space, but it is recommended for use because of its relatively low cost and nontoxic properties.

c. Supply Oxygen.

(1) *Chlorate candles.* These candles are presently used in mining and tunneling operations. They are packaged in cast blocks, 4¾ inches in diameter by 10 inches high. They include a primer and firing cap. Each candle of the above dimensions provides 63 cubic feet (1.8 cu m) of oxygen (enough for about 75 people) and burns for 1 hour. About 0.24 pound (108.9 gm) is required per man-hour. They require a special oven to filter out dangerous gases. This method is one of the most economical for maintaining a satisfactory chemical environment during a sealed-in period. These conditions require a special oven which should be furnished at purchase. They should have accompanying filters to take out dangerous gases that are produced.

(2) *Compressed oxygen tanks.* When commercially available, this is a very economical source of oxygen. If weight and storage are not a problem, this method is useful and convenient. A plus feature is that no heat is released in its use.

d. Absorb Carbon Dioxide and Release Oxygen.

(1) *Sodium superoxide.* This chemical is available in bulk and is water activated. Approximately 0.3 pound (136 gr) is reuqired per man-hour to maintain levels of carbon dioxide and oxygen. Retarding factors here are its relatively high cost. It also constitutes a fire hazard.

(2) *Potassium trioxide.* This material is available in 15-pound canisters. Approximately 0.37 pound (167.8 gr) is required per man-hour to maintain safe levels. It must be replaced at 1½-hour intervals. This material also reacts with water and may create a fire hazard.

Section III. AIR CONDITIONING

99. Mechanics

Air conditioning is the control of temperature, humidity, motion, and purity of air to meet certain human requirements. This is generally accomplished by a refrigeration cycle. A typical cycle is shown in figure 105. A liquid refrigerant under pressure is further compressed at *A*. The refrigerant then passes through the condensing coil *B* where much of the heat created by the previous mechanical compression is removed. The refrigerant is then expanded at *C* and proceeds on through an evaporator coil at *D*. In the expansion process, heat is extracted from the air that is circulated by the evaporator fan.

100. Self-Contained Air Conditioners

a. One or more self-contained air conditioners for each room or zone will simplify the zoning and control problems, improve overall dependability, and avoid the use of long ducts and insulation. However, the overall efficiency of a zoned system usually is not so high as a central unit and the problem of noise can become burdensome. Most military air conditioning units are designed as split units. That is, the evaporator section can be mounted within the shelter and the condensing section can be installed at a distance from the shelter either at the surface, for air cooling, or within the underground installation, for water cooling. If an air-cooled condenser coil is used, it is suggested that the coil and fan be mounted horizontally in a missile-proof kit. Such an arrangement has not been fully blast tested to date, so there will be an unknown degree of vulnerability present with an exposed condensing section. By fabricating a heat exchange tank and submerging the condensing coil in it, an underground reservoir or well can be used for heat dissipation. It is necessary to control man-

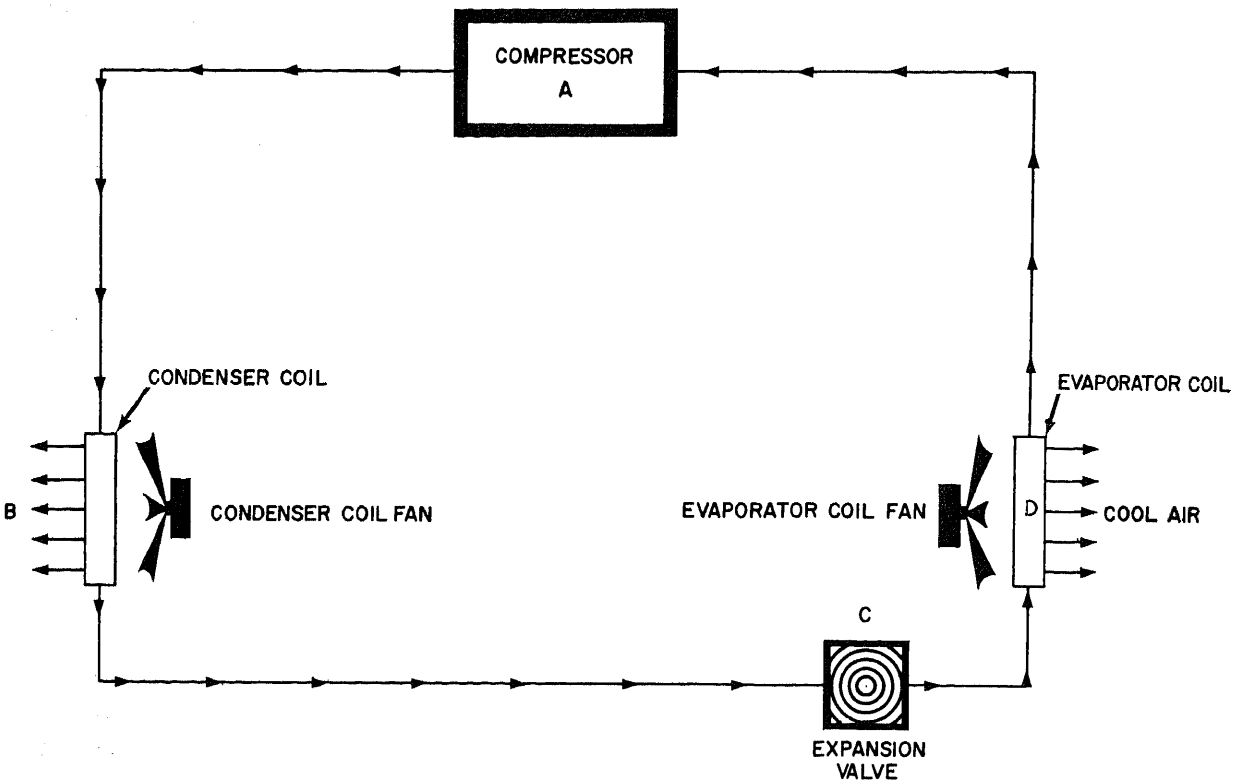


Figure 105. Typical air-conditioning cycle.

ually the flow rate through the tank or have it thermostatically controlled to insure a somewhat constant water temperature around the condensing coil. Several of the units listed in table XXII can be readily adapted for the direct entry of ventilation air from CBR filter units. The air conditioners listed are equipped for the free discharge of conditioned air and the free intake of room air. However, ductwork can be used with appropriate correction for fan performance.

b. The installation of air conditioning equipment should follow the manufacturer's recommended installation procedures. Some type of shear connection for each line leaving the shelter is necessary at the soil structure interface. Some suggested techniques are shown in figure 121.

101. Selection Procedure

Four basic considerations are involved in the selection of a military air conditioner for shelter usage—design, total cooling load, calculation of load, and selecting a unit.

a. Design Conditions. Since almost all military air conditioners are designed to operate from 95° to 125° F. (35° to 51.6° C.) DB at the condenser, there is little need for any selection adjustment for most of the installations considered. The temperature within the shelter will vary from 65° to 90° F. (18.3° to 32.2° C.) and various wet bulbs, depending upon the usage of the shelter. An 85° F. (29.4° C.) ET is considered to be the most severe temperature used for design of a personnel type shelter, assuming overcrowded occupancy. For most installations that require a functional occupancy for a rather long duration, it is suggested that 75° F. (24° C.) DB with a 50 percent relative humidity can be used for design conditions.

b. Total Cooling Load. Since many installations use large amounts of equipment, attention must be paid to the sensible versus latent heat loads. Field experience indicates that the ratio of cooling air flow to load must be greater in equipment cooling applications than in the normal comfort cooling applications wherein a relatively high ratio of latent to sensible cooling exists.

c. Calculation of Cooling Loads. The net cooling load of an underground space is the sum of all internal loads, minus the heat absorbed by the surrounding soil or rock. Since the rate of heat absorption in the surrounding soil decreases with time, the net cooling load during a period of continuous occupancy approaches the sum of all internal loads within the space. A good design technique is to base the cooling load on the sum of all internal loads. The internal load is composed of heat and moisture from personnel, engines, electric motors, lights, communication equipment, and other associated sources. A rough approximation for the heat from a motor driving a machine, such as a lathe or grinder, is that all of the energy used appears as heat in the surrounding space. If the motor drives a pump or an air blower, a fraction of the input energy is imparted to the fluid being pumped, but this can be disregarded. To be safe, the entire electric load consumed within a shelter is considered as being converted to heat. If the electric motor should be located outside the shelter, only the mechanical energy transmitted to the shelter environment would be considered heat. Other equipment, such as radios, may transmit energy to the outside. However, the ratio of energy released is low compared to heat released in the shelter. Therefore, the full input of electric current to this equipment is considered as being converted to heat. Electric lights convert all their input energy into heat. In general, personnel and cooking are responsible for both sensible and latent heat. Electrical equipment liberates principally sensible heat. Some useful relationships for energy conversion are as follows:

1 KW = 3,412 BTU/hr (859,824 cal/hr) and
1 HP = 2,545 BTU/hr (641,341 cal/hr)
$\therefore$ 1 HP = 0.746 KW

Illustrative Example: A 5-HP electric motor drives an air blower. The approximate heat load from this unit is: Electrical equipment produces sensible heat. The sensible heat production is: (Efficiency is 65%.)

$H_s = 5 \times 2545 \times .65$

H_s = 8271 BTU/hr (2,084,292 cal/hr)

d. Unit Selection. After determining the design conditions and calculating the cooling load, the proper unit can be selected by referring to

Table XXII. Air Conditioner Data

Unit capacity	Minimum cooling capacity	Heating capacity	Power source	Power consumption	Evaporator air flow	Maximum operating weight	Operating temperature range
6,000 [1] BTU/hr (1,512,000 cal/hr)	6,000	5,120	208 V, 3 ∅*, 400 C, AC, or 115 V, 1 ∅, 60 C, AC	1.72 KW or 1,720 W	200 cfm (5.66 cu m/min) at 0″ SP	110 lb (49.89 kg)	60°F. to 125°F. (15.5°C. to 51.6°C.)
9,000 [1] BTU/hr (2,268,000 cal/hr)	9,000	None	A–120 V, 1 ∅, 60/50 C, AC B–208/416 V, 3 ∅, 400 C, AC	A–1.8 KW or 1,800 W B–2.2 KW or 2,200 W	300 cfm (8.49 cu m/min) at .2″ water pressure	225 lb (102.06 kg)	60°F. to 125°F. (15.5°C. to 51.6°C.)
18,000 [2] BTU/hr (4,536,000 cal/hr)	18,000	None	A–208 V, 3 ∅, 60 C 120 V, 3 ∅, 60 C B–230 V, 1 ∅, 60 C 115 V, 1 ∅, 60 C C–208 V, 3 ∅, 400 C 416 V, 3 ∅, 400 C	A–3 KW or 3,000 W B–3 KW or 3,000 W C–3.6 KW or 3,600 W	800 cfm (22.66 cu m/min) at .25″ water pressure	565 lb (256.28 kg)	60°F. to 125°F. (15.5°C. to 51.6°C.)
FSN 4120–542–4268; 36,000 [2] BTU/hr (9,072,000 cal/hr)	32,500	None	120 V, 3 ∅, 60 C, AC or 208 V, 3 ∅, 60 C, AC	6 KW or 6,000 W	1,100–1,300 cfm (31.15–36.82 cu m/min) at .20″ water pressure	810 lb (367.42 kg)	60°F. to 125°F. (15.5°C. to 51.6°C.)
FSN 4120–791–9459; 38,000 [3] BTU/hr (9,576,000 cal/hr)	38,000	35,800	208/416 V, 3 ∅, 400 C, AC	11 KW or 11,000 W	1,100 cfm (31.15 cu m/min) at .03″ water pressure	350 lb (158.76 kg)	60°F. to 125°F. (15.5°C. to 51.6°C.)
FSN 4120–739–4321; 60,000 [3] BTU/hr (15,120,000 cal/hr)	60,000	None	208/416 V, 3 ∅, 60 C, AC	11.4 KW or 11,400 W	1,700–1,900 cfm (48.14–53.81 cu m/min) at 1.5″ water pressure	1,150 lb (521.64 kg)	0°F. to 125°F. (—17.7°C. to 51.6°C.)

*∅ = Phase.

[1] This air conditioner is divided into two sections that are connected by flexible, quick disconnect, precharged refrigerant lines and electrical cables. The length of refrigerant and electrical lines should be specified.

[2] This unit is constructed in five individual sections: compressor, condenser, condenser fan, evaporator, and evaporator fan. These units can be arranged in numerous configurations. However, they are not supplied with quick disconnect refrigerant lines.

[3] A collective protector filter inlet connection is provided on the bottom of the unit for installations requiring protection against chemical, biological, and radioactive contamination. An auxiliary evaporator air blower is required for these installations.

Table XXIII. Cooling Capacity Multiplier

Capacity		External static pressure				
BTU/hr	Cal/hr	0″	0.25″	0.50″	0.75″	1.0″
6,000	1,512,000	*	0.96	0.91	0.85	0.79
9,000	2,268,000	--	*	0.96	0.93	0.87
18,000	4,536,000	--	*	0.98	0.96	0.92
36,000	9,072,000	--	*	0.98	0.96	0.92
38,000	9,576,000	*	0.98	0.96	0.95	0.91
60,000	15,120,000					

* Indicates rated resistance.

table XXII. It is strongly suggested that two or more smaller units be selected rather than one large unit. This will insure a greater degree of cooling reliability for an installation. When supply or return ducts are attached to the unit, the external static pressure can be estimated by the procedure outlined in paragraphs 103 through 105. Reduction of the cooling capacity expressed as a multiplier is then determined from table XXIII. If the external static pressure is beyond the range of the cooling unit, a booster fan external to the unit can be used.

e. Operating Criteria. After selecting the unit the appropriate dimensions and configurations for the selected unit can be obtained from paragraph 102.

f. Illustrative Example.

GIVEN: Design conditions:

- Ambient air—125° F. DB and 75° F. wet bulb
- Conditioned air—78° F. DB and 65° F. wet bulb (50% relative humidity)
- Occupancy—100 people
- Ventilation air—3 cfm/person, or 300 cfm total
- External static pressure—0″ free air delivery
- Power source—220-volt, 60-cycle, 3-phase
- Motor-powered electrical and communication equipment power demand is 30 kw.

FIND: Cooling load

SOLUTION:

	Latent heat load	*Sensible heat load*
Internal cooling load:		
Personnel—		
100 people; sensible = 300 BTU/hr and latent = 100 BTU/hr, per person ----	30,000	10,000
(See table XX, using DB temperature of 75° F.)		
Equipment—		
1 kw converts to 3412 BTU/hr		
30 kw x 3412 = --	102,360	
Ventilation air—		
Heat load from cooling 300 cfm of fresh air from 125° F. DB to 78° F. DB. (Since moisture content is low, assume all this is low, assume all this is sensible load.)		

$$H_s = \frac{Q \text{ cfm} \times 60 \text{ min/hr} \times \Delta t}{50}$$

Where Δt means inside temperature minus outside temperature $(T—T_o)$

$$= \frac{300 \times 60 \times 47}{50} = \text{ -- } 16{,}900$$

	Latent heat load	*Sensible heat load*
Heat loads ----------	149,260 BTU/hr	10,000 BTU/hr

Total heat load = 87,600 BTU/hr

$$\text{Sensible heat ratio} = \frac{149{,}260}{159{,}260} = .938$$

For a sensible heat ratio of less than 1.0, a reduction in the cooling load required is permissible. This reduction can be calculated by the following rule-of-thumb: For each 0.1 less than 1.0 for sensible heat ratio, reduce the required cooling load by 5 percent. In the case at hand, a conservative selection can be made from table XXII. In this case, the following units should be adequate since there is only a very small latent heating load.

Two 60,000 BTU/hr
Two 18,000 BTU/hr

102. Physical Dimensions of Standard Military Air Conditioners

The dimensions of standard air conditioners are shown in figures 106 through 111.

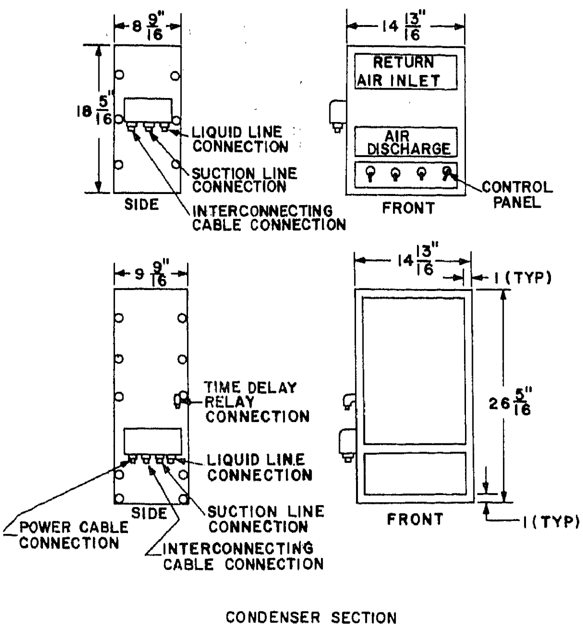


Figure 106. 6,000 BTU/hr air conditioner.

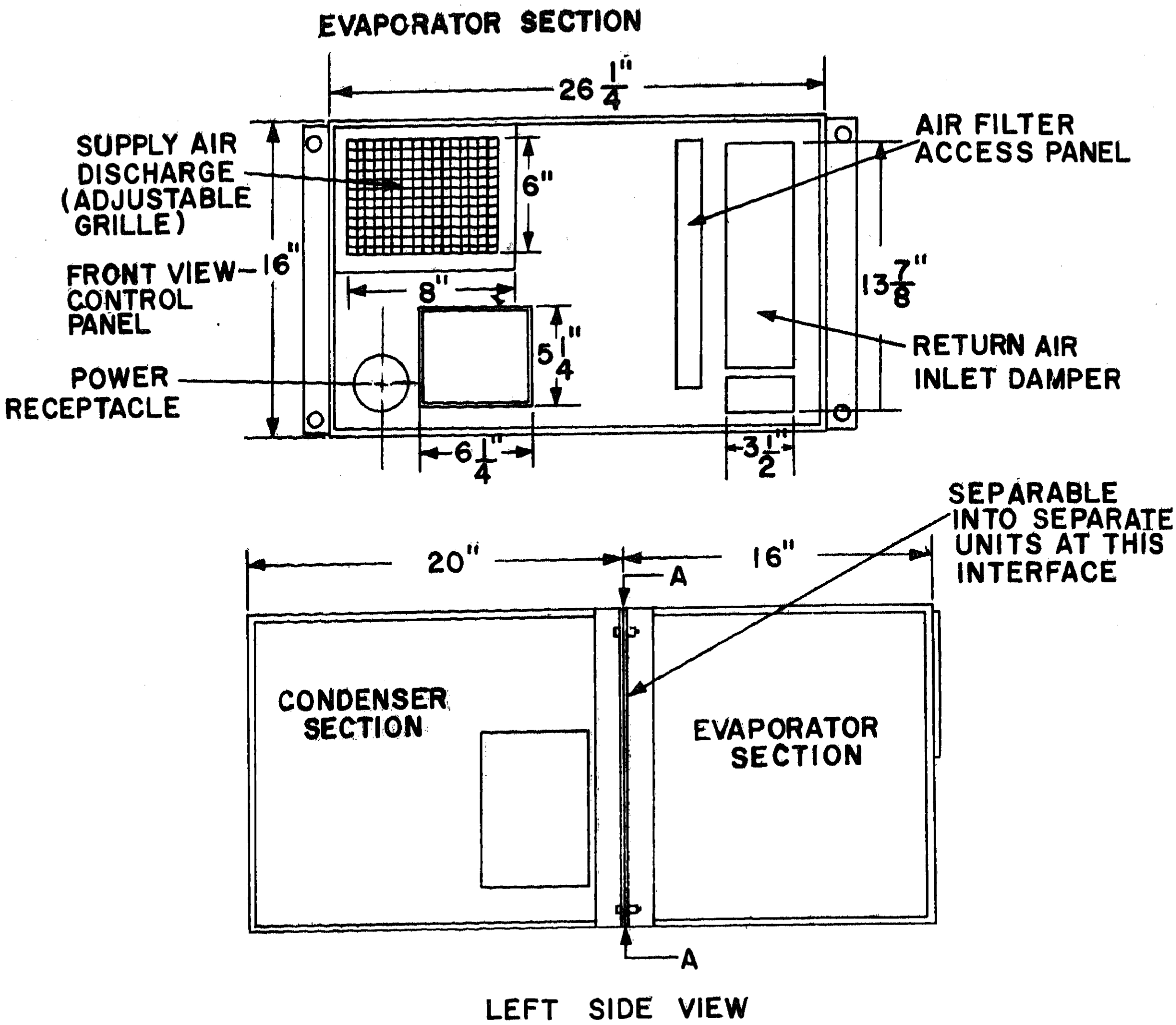


Figure 107. 9,000 BTU/hr air conditioner.

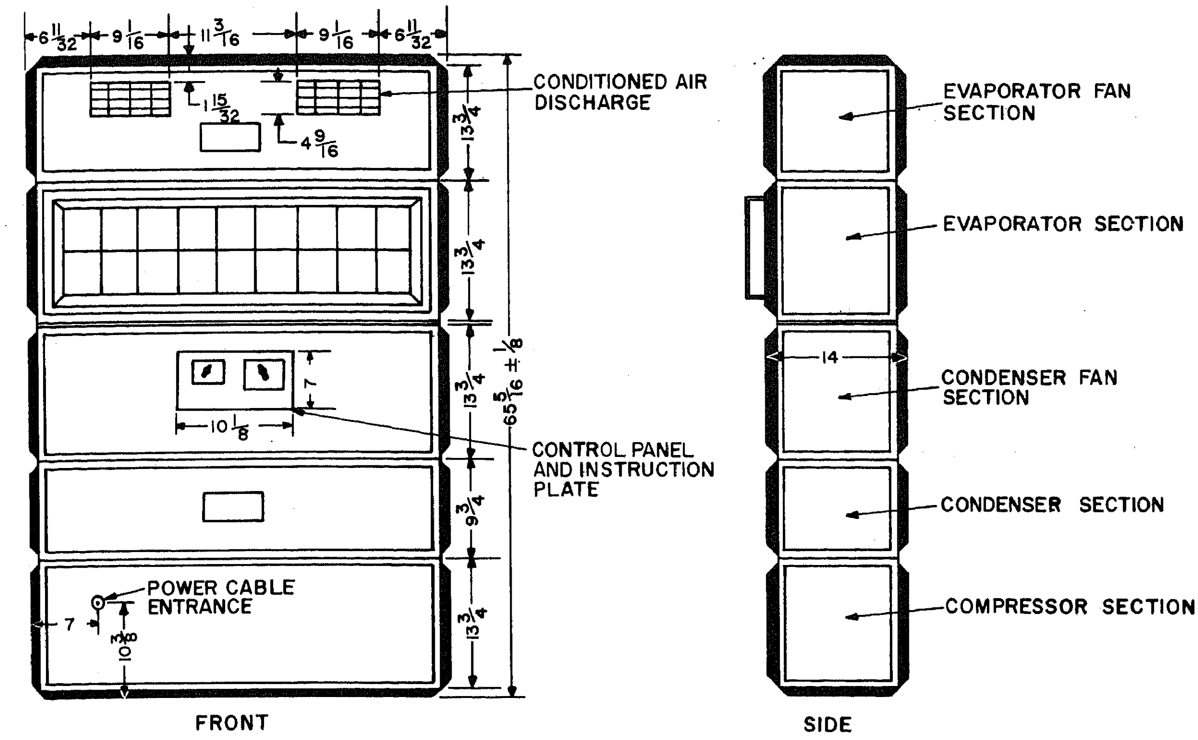


Figure 108. 18,000 BTU/hr air conditioner.

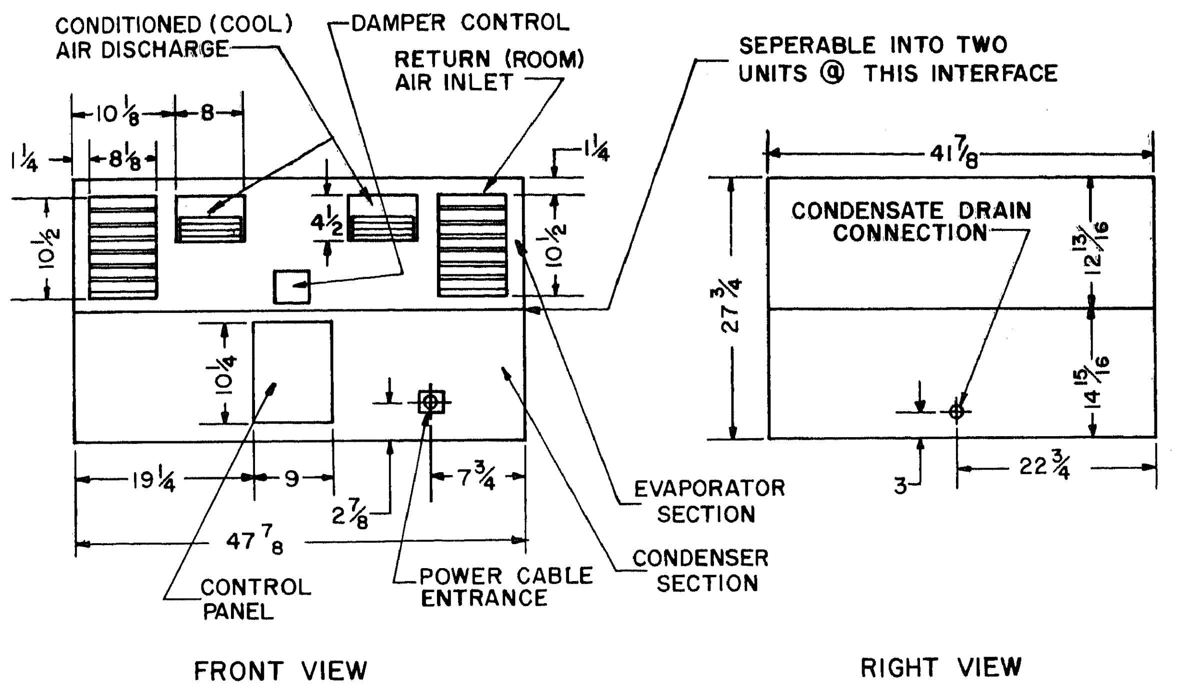


Figure 109. 36,000 BTU/hr air conditioner.

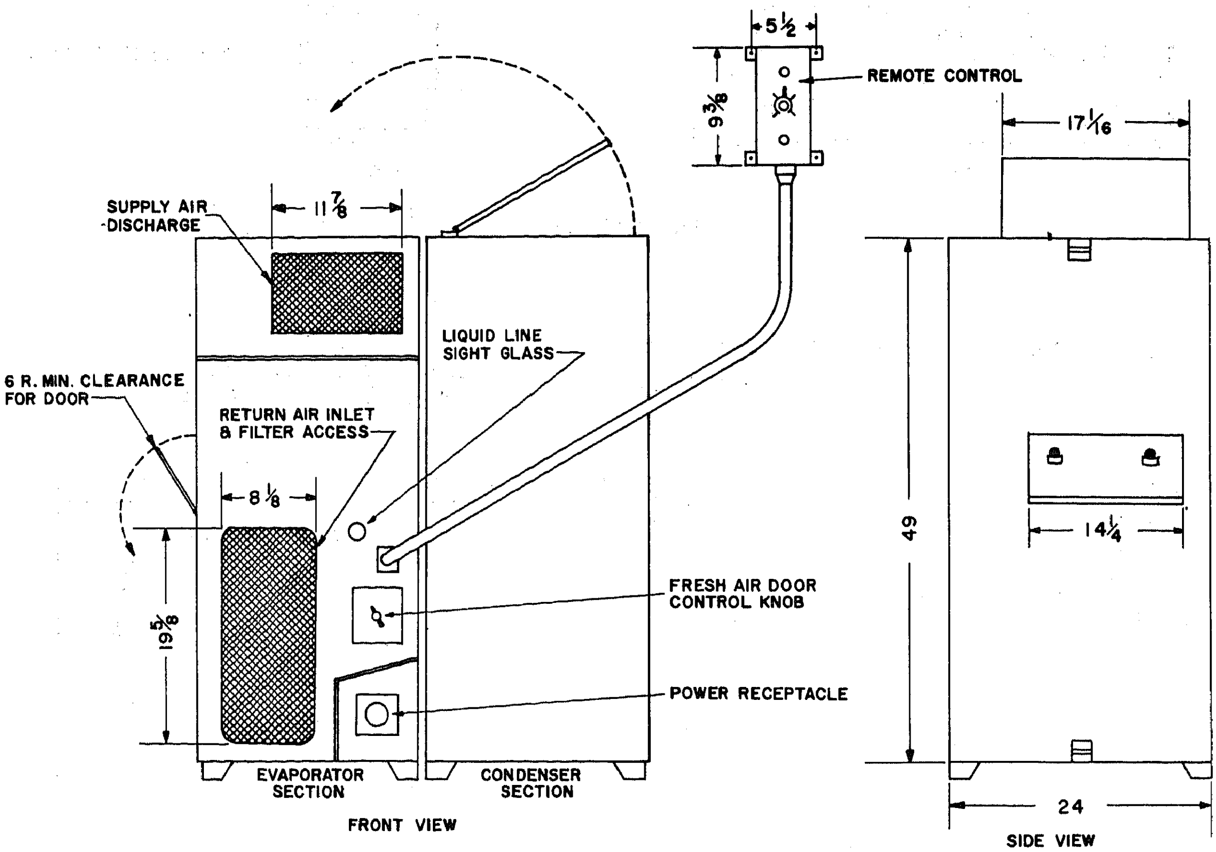


Figure 110. 38,000 BTU/hr air conditioner.

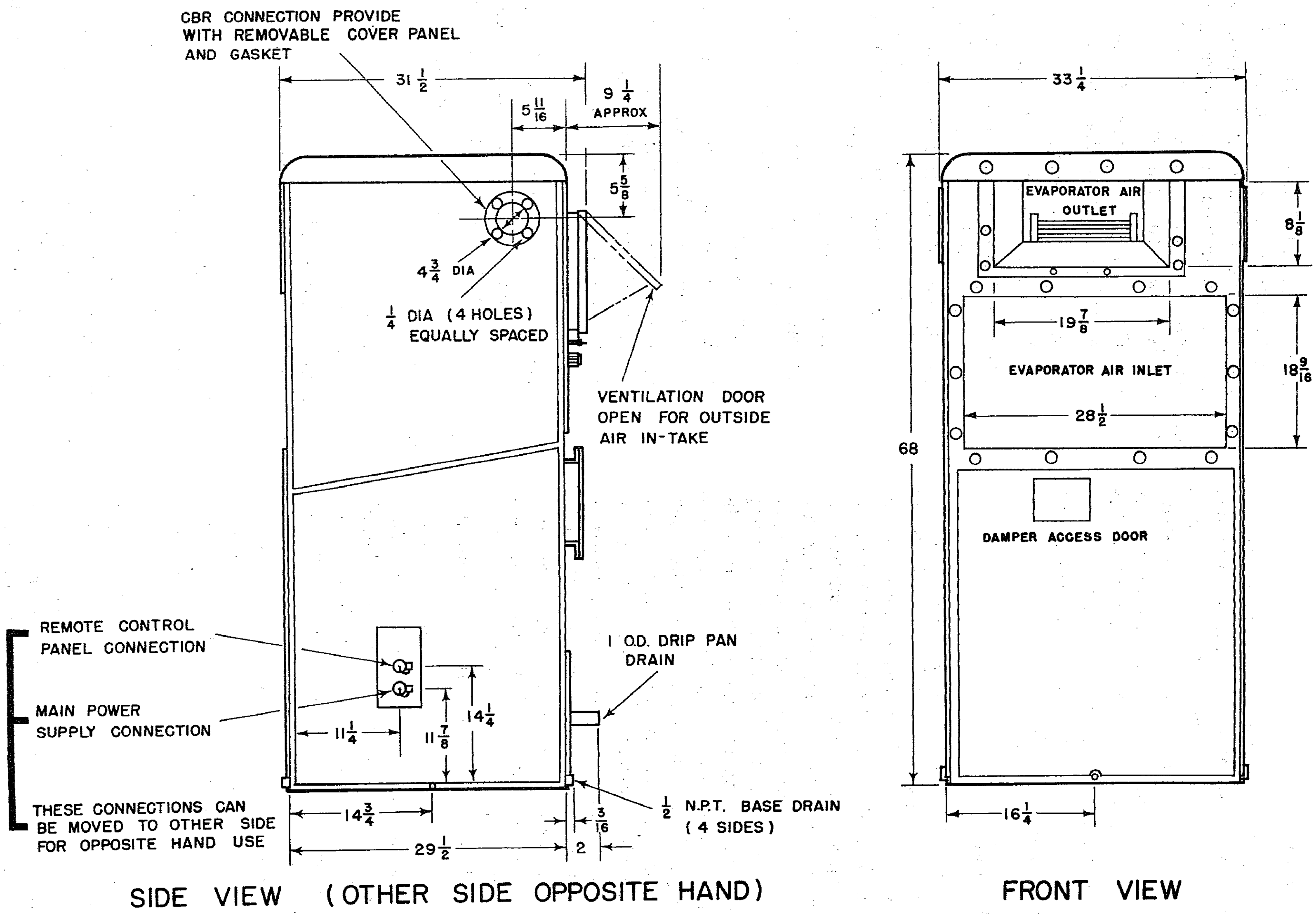


Figure 111. 60,000 BTU/hr air conditioner.

Section IV. DUCT SYSTEMS

103. Definition

The term "duct system" usually signifies an arrangement of sheet-metal conduits designed to contain and direct the flow of air from a source such as an air conditioner to a space being served and back again either to the source or to the inside. Air returned to the source is usually called recirculated air. Exhaust air or vitiated air must be placed in the system by fresh outside air.

104. Design

a. Air Supply. For the design of a duct system, the air supply required for each space served and for the whole system must be determined. This is usually based on the heating- and cooling-load estimates and the outside air requirements. For heating any space by means of air, the heat delivered by the air must equal or exceed the heat loss. For cooling, including dehumidifying a space, the airflow must be sufficient to carry away both the heat and the water vapor liberated in the space. The duct-design procedure usually employed for cooling air-conditioning systems is likely to be applicable in most cases. This procedure is based on the properties of standard air, but the data given in tables and charts are considered sufficiently exact for practical use with air near normal atmospheric pressure (50° to 90° F. or 10° to 32.2° C.) and at any relative humidity.

b. Materials. Sheet iron for ducts in underground spaces should be galvanized or otherwise treated for corrosion resistance. Aluminum of the type ordinarily furnished is considered satisfactory for most purposes, but this metal is subject to attack by caustic substances and should not be used in contact with masonry or concrete, or exposed to the drip or seepage of water containing lime or other caustics. Resistance of aluminum to acid is satisfactory.

c. Velocities. High velocities (actual air particle movement in fpm) are to be favored in underground installations because their use permits the ducts to be smaller. Space underground must be excavated from rock or soil, so the use of smaller ducts, requiring less space, often results in lower man-hour requirements.

d. Calculations of Resistance. The resistance must be known in order to calculate the total air flow and the pressures maintained within the shelter. A simplified procedure for calculating resistance of survival shelter ventilating systems is recommended as follows:

(1) Calculate the number of duct diameters* of the pipe that will be used.

(2) Allow the following:

- (*a*) 7 diameters for a 45° elbow.
- (*b*) 10 diameters for a 90° elbow.
- (*c*) 18 diameters for a 180° elbow.

(3) Divide the total number of duct diameters by 38 to get the number of velocity heads, then add the velocity for reducers, allowing .05 for each reducer used.

(4) Multiply the number of velocity heads** by velocity pressure from table XXIV.

(5) Determine the friction of the intake system from table XXIV.

(6) Determine the friction of the filter(s) from the graph in figure 97.

(7) Calculate the total friction.

e. Illustrative Example.

GIVEN: 300 cfm, 20-foot duct work (6-inch diameter (0) duct), five 90° elbows, one 180° elbow, and two reducers.

FIND: Total resistance of the system

SOLUTION:

Length of duct in duct diameters_____	$\frac{20 \times 12}{6} = 40$
Elbows expressed in duct diameters_____	$5 \times 10 = 50$
	$1 \times 18 = 18$
	108
Divide by 38 to get number of velocity heads__________	$108/38 = 2.84$

* The term "duct diameter" refers to the method used to compute frictional loss of discharge pressure (determined by the diameter of the duct and the length of the duct) in one term.

** The term "velocity head" means the frictional loss in the duct in terms of inches of water gage ("W.G.") pressure.

Allow for the reducers	2 × .05 =	0.10
Total number of velocity heads		2.94
Velocity heads × velocity pressure ("W.G.")	2.94 × .146 =	.43″
Filter resistance		.08″
Total resistance of system		.400″
		.91″

f. Protection Against Fallout. Because of the effects of winds and variations in settling velocities, fallout from high-altitude radioactive cloud formed by a nuclear detonation is distributed downwind in accordance with particle sizes. Particles having mean diameters of less than about 50 microns undergo radioative decay during their prolonged descent and would probably be deposited beyond the acutely hazardous area. Particles having mean diameters of more than 100 microns or terminal velocities higher than 150 ft/min (45.7 m/min) can be largely excluded from a ventilating system by an air intake fixture of the proper configuration. Such a configuration has a turned-down mouth and a mesh prefilter element. A pipe with a gooseneck at its terminal end acts as a gravity separator (fig. 112).

105. Acoustical Treatment

In a confined underground shelter, sound reverberation may become a severe problem.

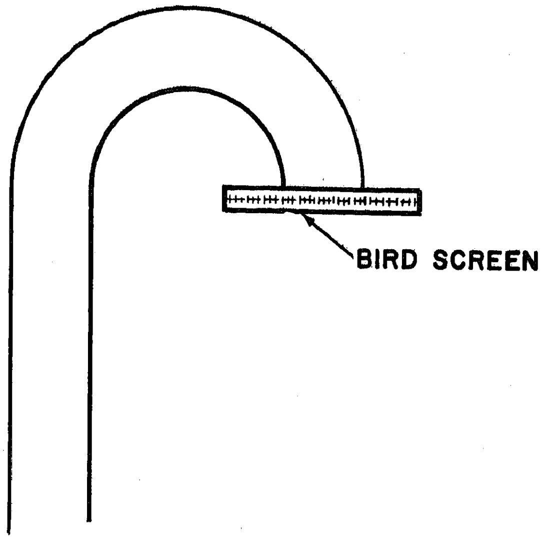


Figure 112. Gooseneck intake.

Table XXIV. Velocity Pressure and Intake Screen[1] Friction (W.G., 70° F., 29.92″ H_g barometer Screen)

Capacity		Dust diameter									
		3″		4″		6″		8″		12″	
cfm	cu m/min	Vel[2] press.	Screen frict.	Vel. press.	Screen frict.	Vel. press.	Screen frict.	Vel. press.	Screen frict.	Vel. press.	Screen frict.
20	0.56	0.014	0.01[3]	0.003	0	--	0	--	0	--	0
30	0.85	0.023	0.01	0.007	0	0.001	0	--	0	--	0
40	1.13	0.042	0.02	0.013	0.01	0.003	0	--	0	--	0
50	1.42	0.065	0.03	0.02	0.01	0.004	0	0.001	0	--	0
75	2.12	0.146	0.08	0.046	0.02	0.009	0	0.003	0	--	0
100	2.84	0.260	0.14	0.083	0.04	0.016	0.01	0.005	0	0.001	0
150	4.24	0.590	0.31	0.18	0.10	0.037	0.02	0.012	0	0.002	0
200	5.68	1.04	0.54	0.33	0.17	0.065	0.03	0.021	.01	0.004	0
250	7.08	1.62	0.84	0.51	0.27	0.10	0.05	0.032	.02	0.006	0
300	8.48	2.34	1.21	0.74	0.39	0.146	0.08	0.046	.02	0.009	0
350	9.91	3.18	1.66	1.0	0.52	0.198	0.10	0.063	.03	0.012	0.01
400	11.36	4.15	2.16	1.31	0.68	0.260	0.14	0.082	.04	0.016	0.01

[1] The intake screen has a 1/2″ x 1/2″ mesh.

[2] For intermediate capacities, 1.0″ velocity pressure is equivalent to 4005 ft/min. The V. P. varies as the square of the velocity.

[3] For the intake screen, 0.3 is equivalent to 3030 ft/min. Friction varies as the square of the velocity.

Some type of acoustical treatment will be required where a low sound level is essential, such as a communications center. It is possible to use acoustical material upon the inside of the corrugated steel arch if air conditioning or dehumidification will remove sufficient water vapor so that wetting by condensation is not a problem. Since the chief sources of noises are air-conditioning equipment, fans, blowers, pumps, and similar equipment, individual treatment of each noise source is an effective method of minimizing noise. Ducts and tubes should be shock mounted and integrally fastened to cut down on ventilating noise.

Section V. FILTER UNITS

106. Types

There are two basic types of filter units—particulate and particulate-chemical. The particulate filter should be of the absolute type, such as the ones that are supplied by the Chemical Corps. This type filter differs from all others in its ability to trap dust and particles which could carry radioactive matter or biological agents. The particulate-chemical filter is one which is capable of removing toxic chemical agents by absorption into activated charcoal and, in addition, of trapping radioactive particles and biological agents. The Chemical Corps supplies filter units for military use. All are of the particulate-filter type. The various sizes are listed in table XVIII with their performance characteristics given in figures 86 through 90.

107. Filter Unit Installation

Filter units should be installed in a readily accessible location, and with enough overhead clearance for periodic removal and replacement of the filter elements. Since the filter elements collect contaminants and in no way neutralize them, the elements become a source of contamination and extreme care should be exercised during handling. Also, the elements can become a very hazardous radioactive source within the shelter and it will be necessary that radiation shielding be provided around the filter unit. The easiest way to provide shielding is to install the filter units below the floor in a pit and place a layer of sandbags or concrete blocks over the access hatch. If the unit is installed at floor level, the following criteria may be used for shielding:

a. For 100 cfm (2.83 cu m/min) intake air systems, a mass thickness* of 40 to 60 psf (19.5 to 29.3 gr/sq cm) should be used.

b. For 1,000 cfm (28.32 cu m/min), a mass thickness of 80 to 120 psf (39 to 58.6 gr/sq cm) should be used.

c. For 10,000 cfm (283.2 cu m/min) and above, a mass thickness of 160 to 240 psf (78 to 117 gr/sq cm) should be used.

108. Pressurization

To exclude any contaminants from the structure, a slight positive pressure (of approximately 0.5 inches of water) must be maintained. To obtain pressurization of a well sealed structure, it is necessary to restrict the outward flow of air. The use of an antibackdraft valve (figs. 91 and 92) and pressure regulators (fig. 94) provide the capability of maintaining the necessary positive pressure. To prevent entrance of contamination due to rupture of the filters caused by high extreme pressures, such as those accompanying a nuclear burst, an M1 anti-blast closure-surge tank assembly (fig. 96) should be positioned in the effluent side of the antibackdraft valve. The graph in figure 97 can be used to determine the performance of the antiblast closure. Installation of the antiblast closure should be within an accessible area while the surge tank may be separated from the structure. See TM 3–4240–203 for further information.

Section VI. POWER, WATER, FOOD, AND COMMUNICATIONS

109. Electric Power and Lighting

a. Battery Power. Battery operated lights are required in every shelter. They are either as an emergency facility for structures using other sources of electric power, or as the only lighting means, *for example,* in emergency

* See paragraph 49 for definition of mass thickness.

Table XXV. Critical Specifications and Operating Characteristics of Standard Generators

Output	Cooling	Length		Width		Height		Weight (dry)		Mounting
		in	cm	in	cm	in	cm	lb	kg	
0.5 KW (AC or DC[1])	Air	24	60.56	19	48.26	21	53.34	102	46.26	Tubular frame
1.5 KW (AC or DC[1])	Air	24	60.56	19	48.26	21	53.34	185	73.91	Tubular frame
3.0 KW (AC or DC[1])	Air	36	91.44	25	63.50	28	71.10	300	136.08	Tubular frame
5.0 KW, AC	Air	45	114.30	29	73.66	34	86.36	500	226.80	Skid
5.0 KW, AC[2]	Liquid	57	144.78	26	66.04	36 plus muffler	91.44	850	385.56	Skid
10.0 KW, AC	Liquid	62	157.48	28	71.10	37 plus muffler	93.98	1,300	589.68	Skid
15.0 KW, AC	Liquid	85	215.90	32	81.28	57	144.78	2,500	1134.00	Skid
30.0 KW, AC	Liquid	105	266.70	36	91.44	66	167.64	3,500	1586.60	Skid

[1] (AC or DC) two different generators.

[2] Liquid-cooled 5 KW being phased out of supply.

Table XXV. Critical Specifications and Operating Characteristics of Standard Generators—Continued

Full load operating characteristics (average or maximum values)

Output (kw)	Fuel	Fuel consumption				Lubrication oil requirement		Intake air requirement		Heat discharge thru cooling system[4]	
		lb/hr	kg/hr	gal/hr	1/hr	lb/hr	gr/hr	cfm	gr/sq cm	B.t.u./hr	cal/hr
0.5	Gasoline	1.5	.68	0.25	0.94	0.01	4.53	3	210.92	7,600	1,915,200
1.5	Gasoline	3.	1.36	0.50	1.89	0.015	6.80	7	492.15	15,000	3,780,000
3.0	Gasoline	5.5	2.59	0.90	3.41	0.03	13.60	18	1,265.54	30,000	7,560,000
5.0	Gasoline	7.	3.17	1.15	4.35	0.05	22.68	46	3,234.16	50,000	12,600,000
10.0	Gasoline	14.	6.34	2.3	8.70	0.10	45.36	52	3,656.01	102,000	25,704,000
15.0	Diesel	18.	8.06	2.4	9.08	0.15	68.04	128	8,999.42	153,000	38,556,000
30.0	Diesel	36.	16.12	4.8	18.17	0.3	136.08	218	15,328.14	305,000	76,860,000

[3] Temperature limits: —65°F. to 125°F. (18.3°C. to 51.6°C.).

[4] Remainder of heat discharged through exhaust. Means must be provided to dissipate heat discharged through the cooling system.

(*Note.* Gasoline stored for 3 months or more may deteriorate.)

Table XXVI. Typical Water-Cooling Requirements for Power Generating Equipment

Type of power	Cooling water in gpm/KW
Diesel	0.54
Gasoline	0.54

shelters constructed for brief occupancy or as storage shelters. Battery power would also be required for emergency or standard communication equipment.

b. Generator Properties.

(1) Electric generators are now used in a variety of sizes from 0.15 KW to 500 KW. Generators of 10 KW and below are generally gasoline driven, single-phase, 120-volt, 60-cycle models, while sizes 15 KW and above are generally diesel driven, 3-phase, 120/208- or 240/416-volt models and may be operated to produce either 50- or 60-cycle current. Standard generators are listed in table XXV.

(2) Emergency generators are usually started manually or with a battery. They are connected to their load through a double-throw switch which also disconnects the load from the normal electric supply lines.

(3) Generator protection is obtained by fused switches or air circuit breakers. Typical design data for cooling-water requirements are found in table XXVI.

110. Belowground Installations

a. Procedure.

(1) Power generators may be installed belowground with a remote radiator installation and a separate forced ventilating system to remove the radiated heat from the unit.

(2) If installed belowground, a gasoline driven generator and the accompanying gasoline storage must be placed in a room or alcove separated from the basic personnel shelter. This may be done by placing the generator and gasoline supplies in a fireproof, gastight room constructed at some distance from the basic structure, or by placing them in a separate structure remotely connected to the main structure but with a thermal, gastight seal

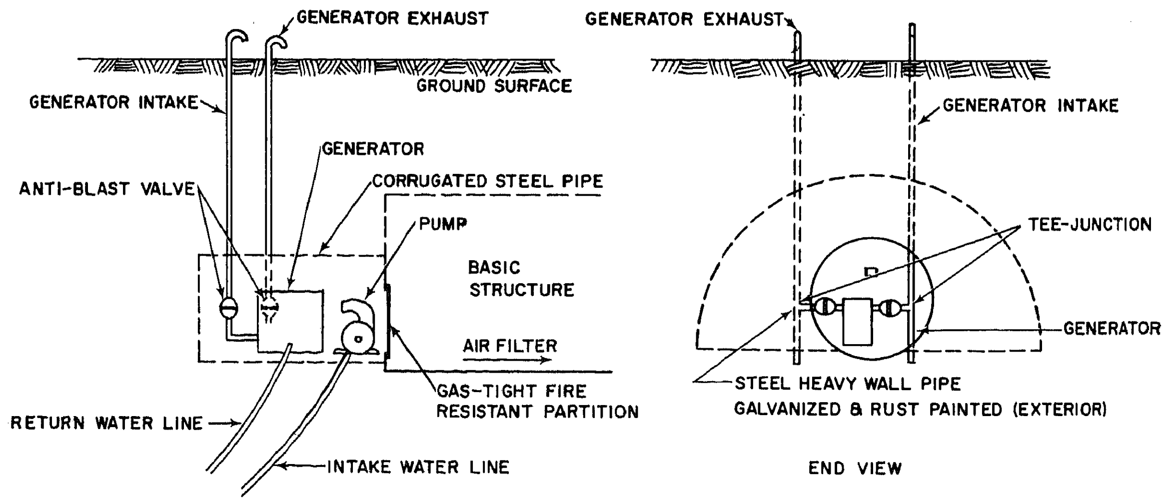


Figure 113. Generator employment, exhaust system.

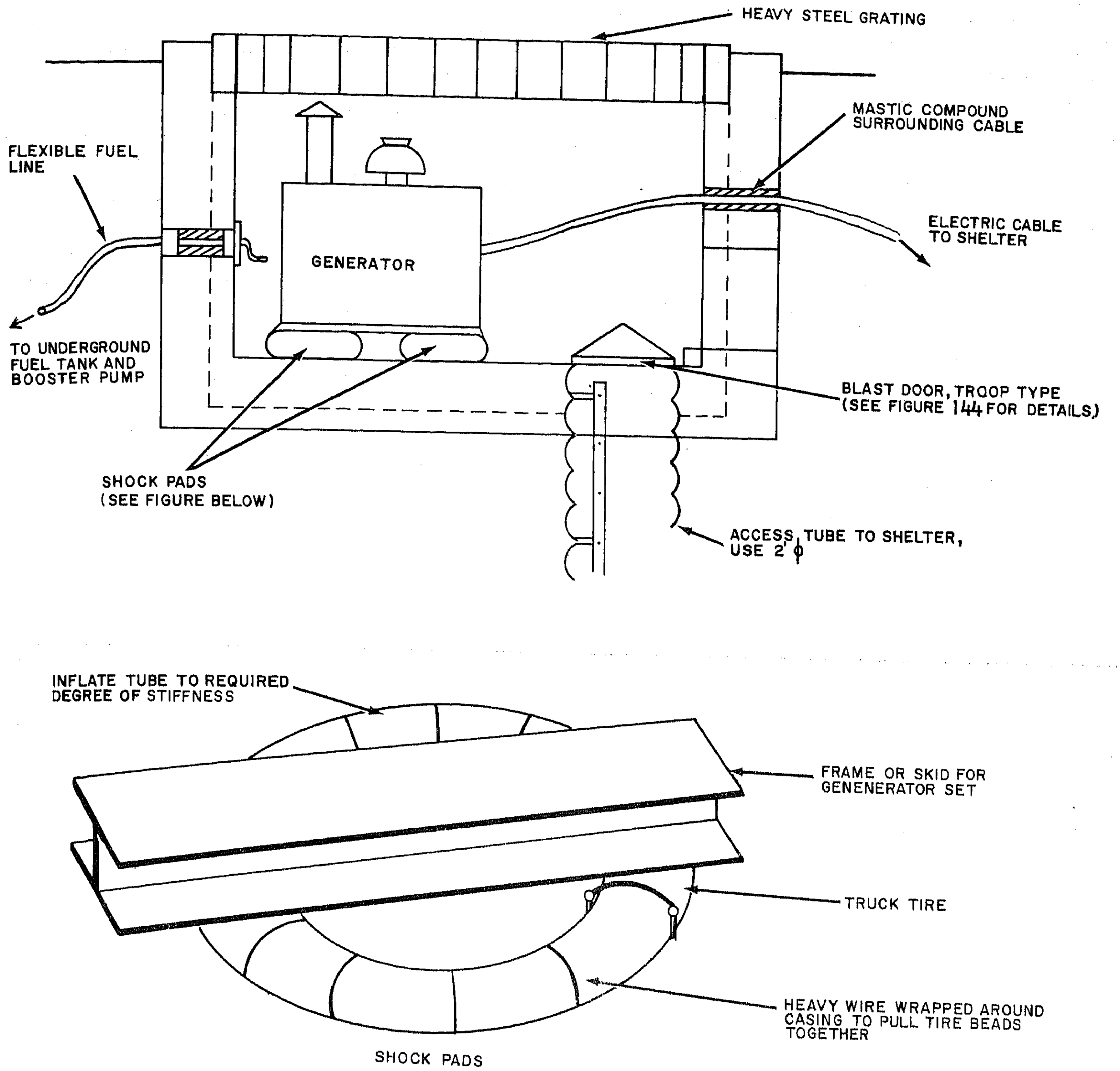


Figure 114. Generator aboveground installation.

between the two. The engine of the generator must be adapted to a belowground installation by providing a blast protected exhaust and intake. Considerable attention must be given to the requirements for cooling the engine and generator.

b. Cooling. If a large body of water such as a stream or lake is available, it can be used as a heat sink for the generator engine. However, a booster pump will be needed to circulate the water through the engine. Some type of thermostatic control with a bypass arrangement will be necessary to adjust the water flow to obtain the optimum engine operating temperature. A typical belowground installation is shown in figure 113.

111. Aboveground Installations

The entire generator set can be located at

the surface of the ground in a blast pit flush with the ground surface. A heavy steel, removable grating should cover the pit to prevent missile and debris damage. Standard generator sets have been tested against fast-rising overpressure up to 50 psi (3.5 kg/sq cm), and the only failures found have been breakage and shear of radiator mountings. A suggested method of aboveground installation is shown in figure 114. It is further suggested that radiator mountings be reinforced with possible additional mountings installed on the generator frame. Electric cables should be carried away from the generator in a trench or conduit separated from the fuelline trench so that a failure of one system cannot communicate to the other.

Table XXVII. KVA Load-Carrying Capacity of Wire (Balanced Load)

Wire size AWG	Maximum amperes	1 ø, 2-wire 120-volt	1 ø, 3-wire 120/240-volt	3 ø, 4-wire 120/208-volt
8	77	9	18	27
6	104	12	24	37
4	137	16	32	49
2	184	22	44	66
Stranded 2	188	22	45	67
0	220	26	52	79
1/0	252	30	60	90
4/0	391	47	94	140
500 MCM	674	82	164	241

*ø — Phase.

112. Conductors

Data for the proper selection of trunk and intermediate electrical cables are as follows:

a. Carry the Load. The conductor must be large enough to carry the load current; if not, it may overheat and burn the insulation or cause a leak in the circuit by melting. The safe current carrying capacity of an electrical conductor depends on the resistance of the material, the cross-sectional area (wire size), and the allowable temperature rise which, in turn, depends on the heat radiation. The allowable temperature rise also depends on the type of insulation used. Heat radiated by wires in a cable is not dissipated as rapidly as the heat radiated by wires in open air. Table XXVII gives the maximum kilovolt amperes (KVA) that can be carried (with maximum current) by various size wires as used in different electrical systems.

b. Prevent Voltage Drop. The conductor must be large enough to prevent excessive voltage drop. If the wire is not large enough, the reduced voltage at the load could prove inadequate for operation of the equipment. Most electrical equipment is designed to operate within +5 to 10 percent of its rated voltage. Consequently, calculation of the expected voltage drop may be important when planning a large distribution system. Except for short distances the determining factor in selecting wire size is the voltage drop, not the load carrying capacity. Figures 115 through 117 are included to aid in computing voltage drop and wire size.

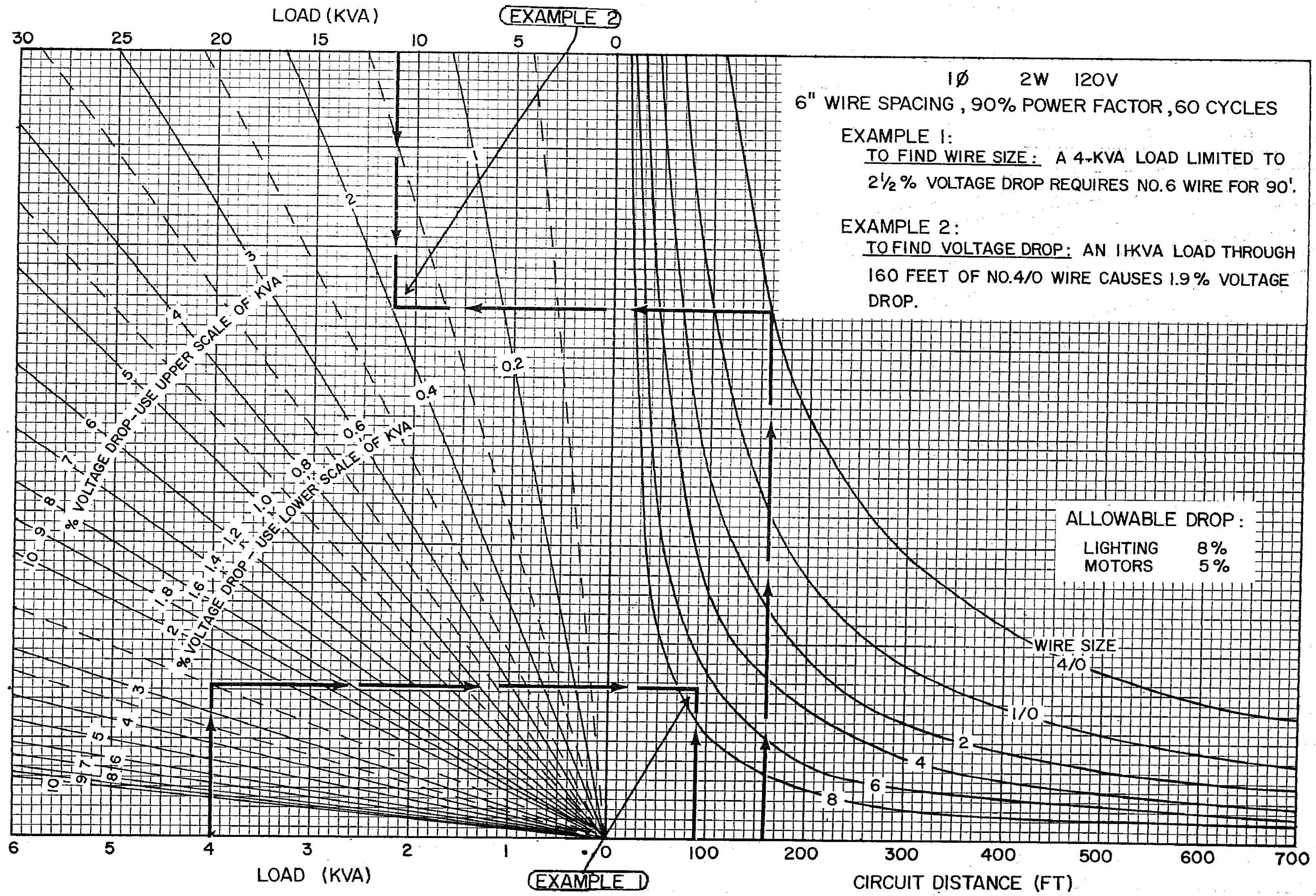


Figure 115. Voltage-drop and wire-size chart for single-phase, two-wire, 120-volt circuit.

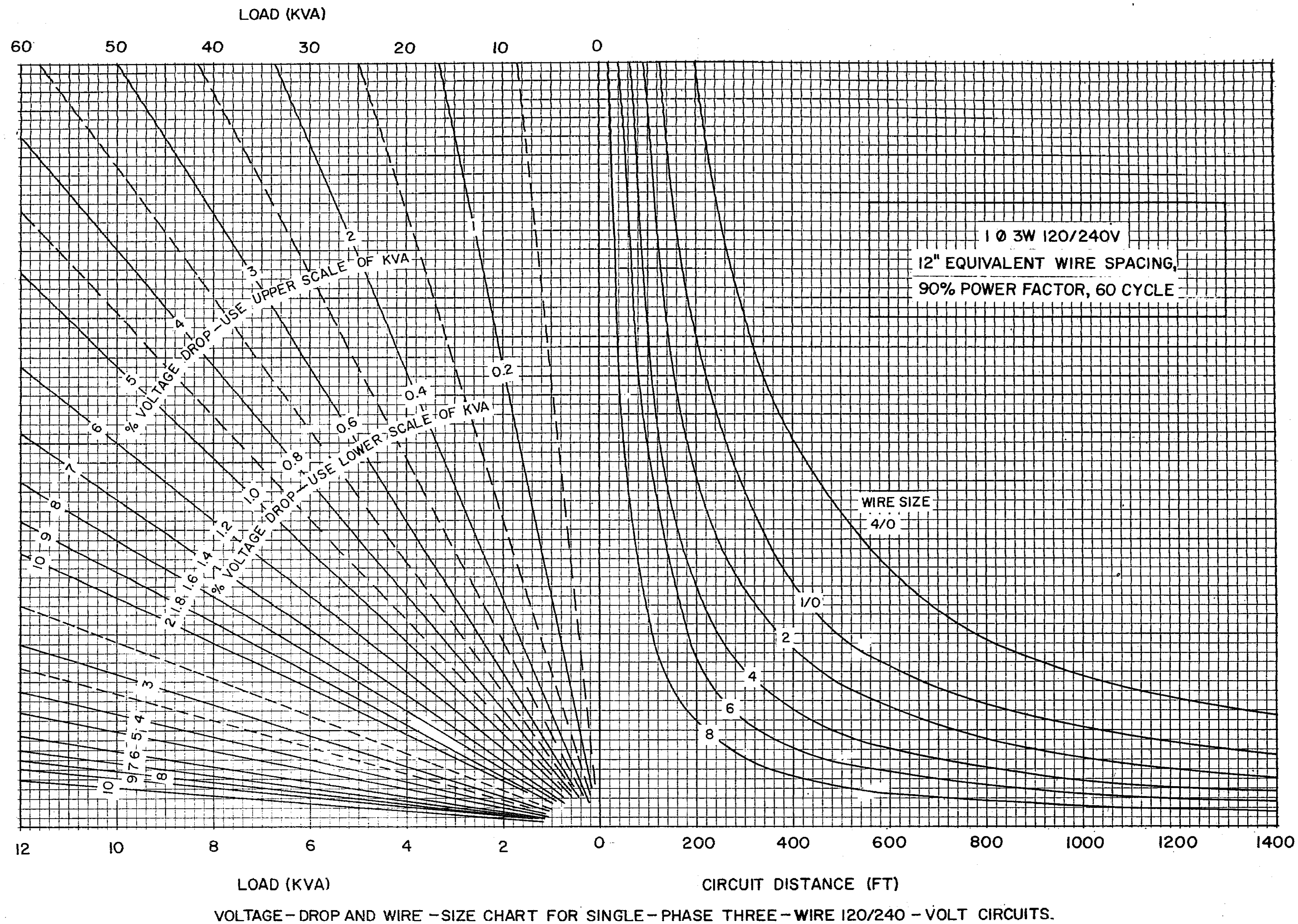


Figure 116. Voltage-drop and wire-size chart for single-phase, three-wire, 120/240-volt circuits.

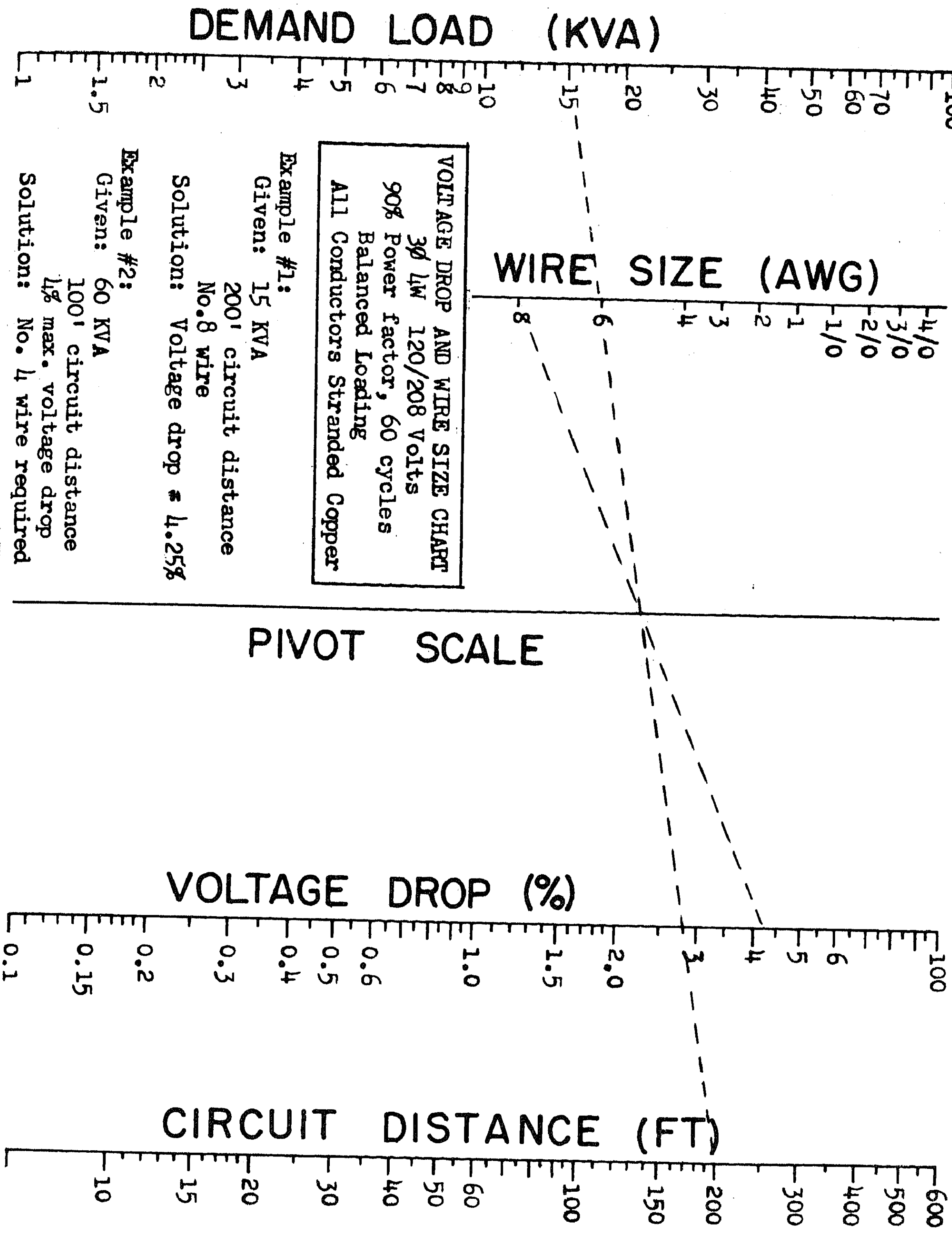


Figure 117. Nomogram—voltage drop and wire size.

Section VII. SANITATION

113. Sanitation Systems

A typical latrine room is shown in figure 118. Several general factors are to be considered in the design of any latrine system. Objectionable odors can be effectively controlled by insuring adequate ventilation in the latrine room and then exhausting the still air to the atmosphere. Since a chemical sanitation system tends to become offensive, it may be feasible to route a part of the exhaust air directly through a sanitary vault or scavenge the vault with a siphon to control odors. For design purposes, it is estimated that there will be a per capita waste production of about 1 gallon (3.78 liters) per day (feces, urine, wash water, garbage, and similar waste materials.)

114. Chemical Latrines

a. Drums and Canisters. Chemical toilets can be made by lining a 24-gallon grease drum or a pressed paper canister of equivalent capacity with a plastic bag. A removable seat with cover may be fitted to the canister, or the canister can be placed in an airtight sanitary vault (fig. 119).

b. Open Containers. Chemical treatment of human waste in open cantainers is possible with any of the following procedures:

(1) Procedure A—Add 473 milliliters (1 pint) of mineral oil each day and 29.5 milliliters (1 ounce) of cupic sulfate with 118.3 milliliters (4 ounces) of sodium bisulfate three times each day.

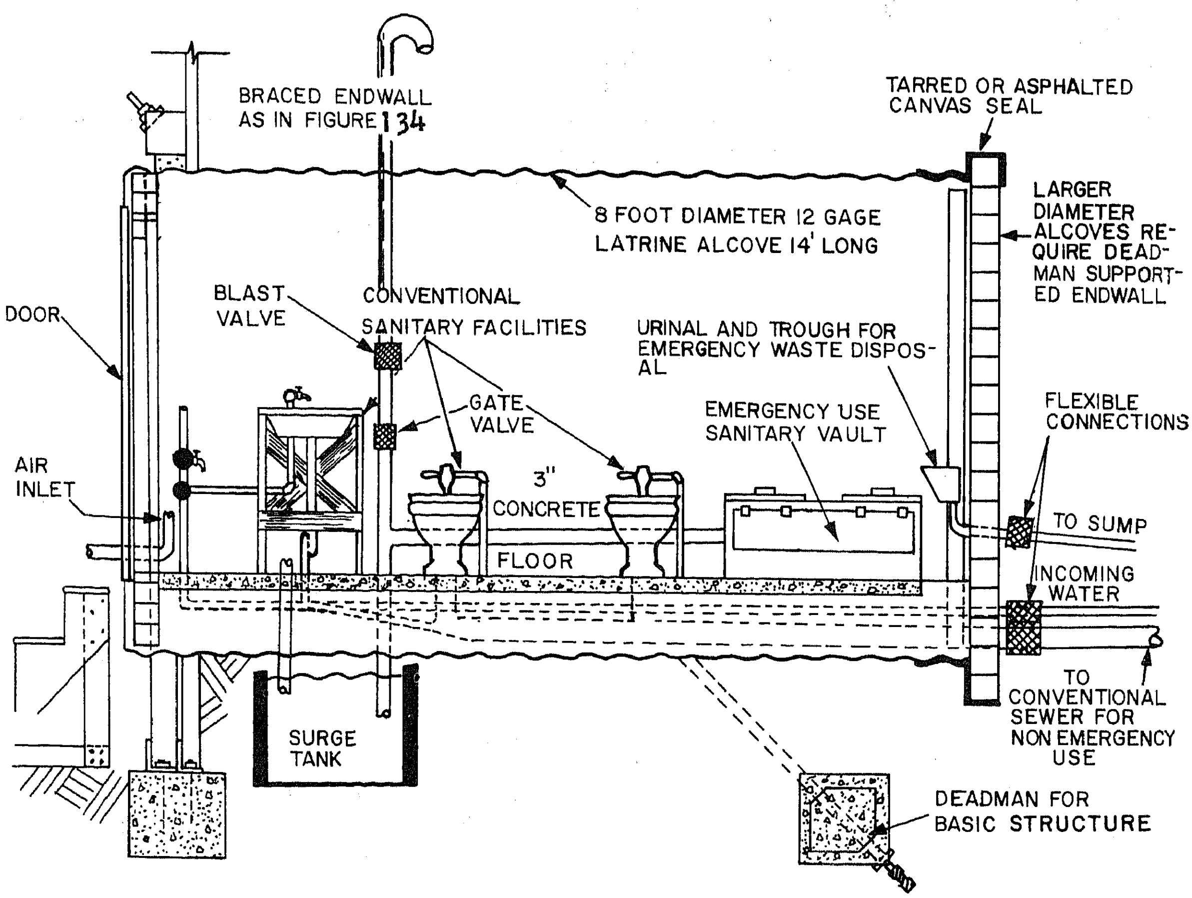


Figure 118. Typical latrine alcove.

(2) Procedure B—Add 473 ml (1 pint) of mineral oil each day and 59.1 ml (2 pints) of boric acid with 29.5 ml (1 ounce) of perborate twice each day.

(3) Procedure C—Add 237 ml (½ pint) of mineral oil each day and 15 ml (½ ounce) of saponified cresylic acid twice each day.

All of the above chemicals are readily available and relatively inexpensive. The mineral oil is added as soon as the liquid level is over the solids. The oil serves as a floating seal to hold down objectionable odors and at the same time slows down the process of decomposition. Some arrangement should be made for temporary storage (maximum of 7 days) within the shelter until waste canisters can be set outside and then be disposed of by burial at some later time.

115. Conventional System

A conventional sanitation system may be used for structures having a piped water supply. However, chemical toilets should be provided as emergency facilities. Outlets should be of cast iron, concrete, or corrugated steel pipe and should carry to a lagoon, to a conventional sewer system, or to a tank type facility. An invert outlet below the surface of a lagoon or stream has the most blast resistance. However, a conventional antibackflow valve and surge tank must be installed to prevent the overpressure from creating a backflow (fig.

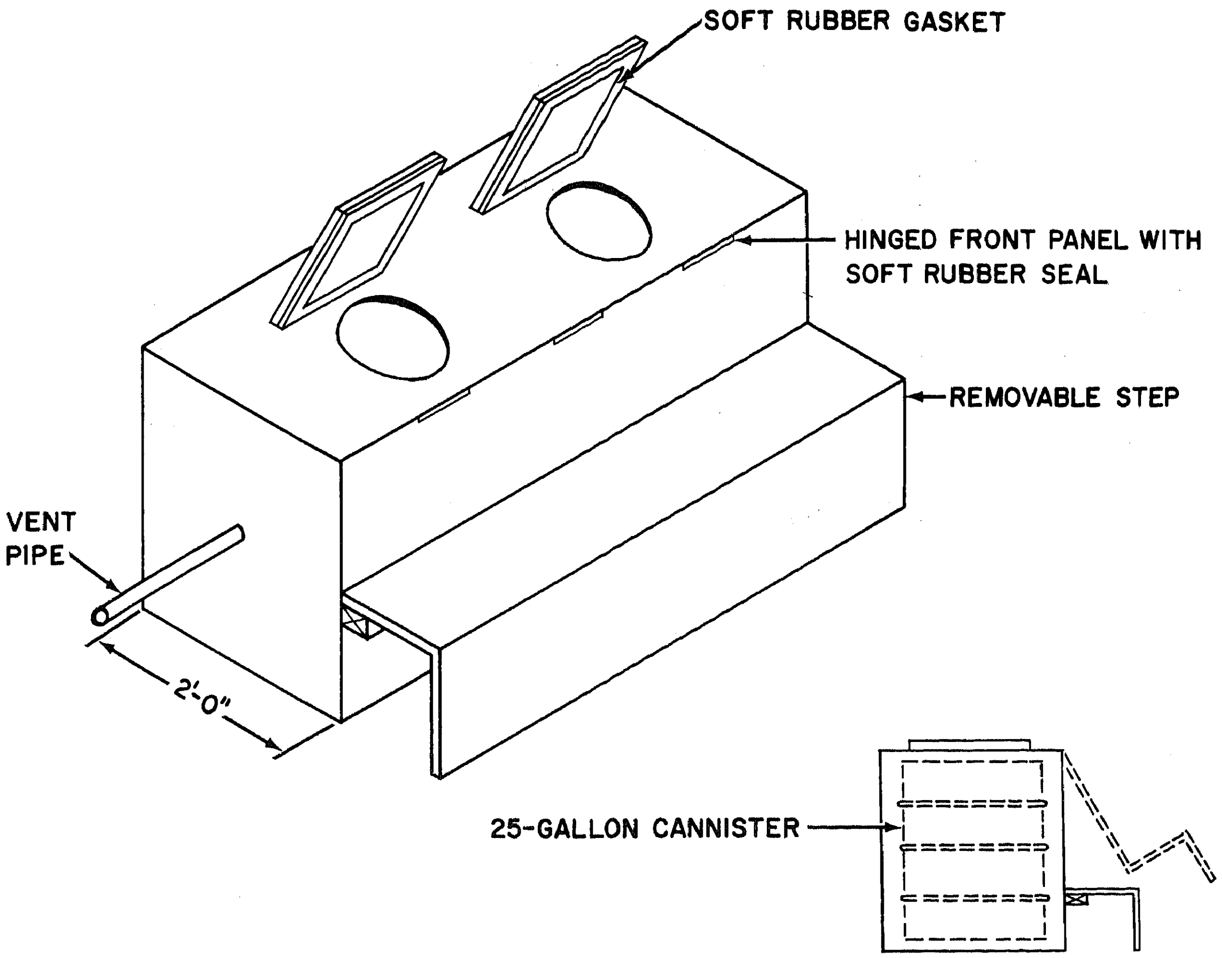


Figure 119. Sanitary vault.

120). Every pipe or line that leaves the shelter should be provided with a flexible coupling at the interface of the line with the structure. Flexible connections are easily made with high strength rubber steam line and hose clamps (fig. 121).

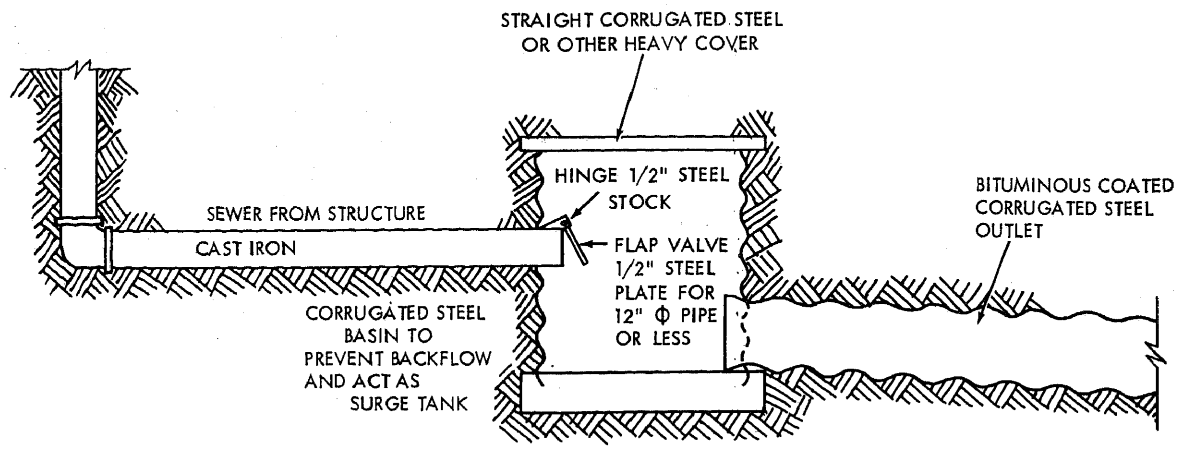


Figure 120. Typical sewer surge tank detail.

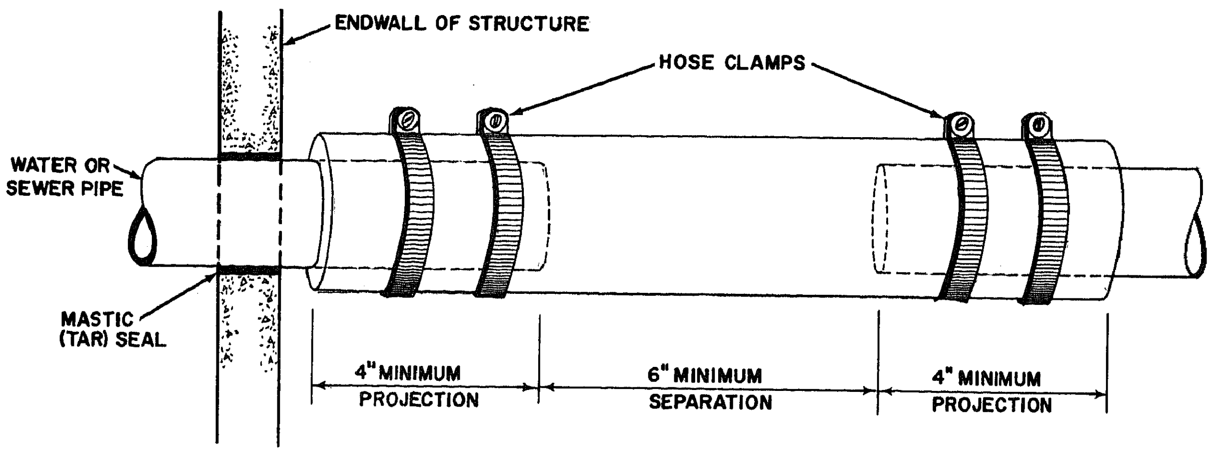


Figure 121. Flexible utility connection.

Section VIII. STORAGE

116. Water Supply

a. Storage. The most readily available means of water storage is with 5-gallon cans stored in the shelter. Water treatment chemicals should be kept on hand for insuring that long-stored water will be potable. A rigid system should be set up for regular replacement of the stored water. The cans should be stored upright, and may be placed within the structure itself or in separate storage areas. The amount of water to be stored depends on the nature of the structure's use, and the duration of the expected occupancy. A minimum of 2 quarts (1.89 liters) per occupant per day for maximmu occupancy should be stored in any protective structure. Drums or tanks used for storage should be within or below the structure to lessen shock effects (fig. 122). They should be

of metal or more flexible construction, and should be located so that drainage because of rupture will be into the subgrade and not onto the floor of the structure. Rubberized storage tanks below the structure floor level could be used for large capacity water storage. Means of exit for emptying and refilling the tanks shoud be provided within the shelter.

b. Water Distribution System. A water distribution system may be provided to supply washing and sanitary needs, depending on the use of the structure, and on storage capacity or water availability. Usually the capacities for storage are such that a hand pump should be enough for normal distribution. However, if there is a rather extensive distribution system, a pump may be used to obtain the required pressures and capacities.

117. Food Supply

Standard packaged rations should be stored in structures intended for long duration occupancy, with their amount and nature depending on the anticipated number of personnel and types of utilities. The most suitable rations for this purpose are *C* and 5-in-1, which are packaged to be moisture resistant. For planning purposes the volume of the standard rations is shown in table XXVIII. Storage space used for the rations may be partitioned to permit the used boxes containing the waste to be stored in areas previously occupied by the full containers Cooking or other refined food service equipment is not considered essential to protective shelters.

Table XXVIII. Volume of Standard Rations

Type ration	Ration package	Wt/package		Volume/package	
		lb	kg	cu ft	cu m
Small detachment, 5-in-1	5	27	12.25	0.8	0.025
Individual, *C* combat	6	40	18.40	1.1	0.031
Food packet, individual assault	24	39	17.69	1.3	0.037
Food packet, survival	24	—	—	0.63	0.018

118. Communications

Signal Corps equipment has been designed to withstand severe shocks or vibrations and

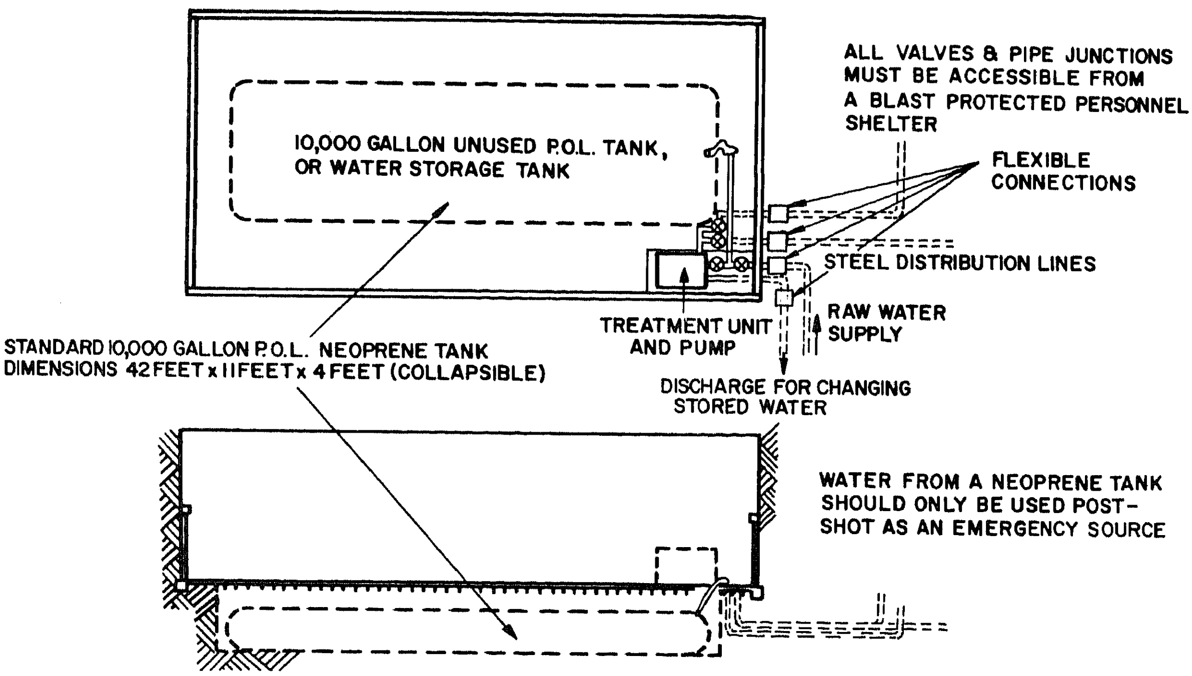


Figure 122. Protected central water supply.

should be adequate in normal placement within a protective shelter. Equipment should not be mounted upon or placed adjacent to outside walls or structural partitions. Wires should enter the structure by protected means as was described for water supply pipes. Entranceways furnish excellent accessibility and a means of avoiding sharp structure-ground differential settlement. Cables may be attached loosely to the basic structure for convenience, but slack should be left in the lines to permit partial deformation of structure under higher-than-designed overpressures. Placement of a telephone within a blast resistant canister close to the structure entrance at ground surface would be advisable to insure ground-structure communications after a damaging attack. A means of ringing or other alarm must be provided with the telephone either in the selection of equipment or in addition to it. Standard signal equipment has the capacity to withstand nuclear shocks as proved by weapons effects tests. A stock of replacement antennas that can be erected and raised from an antenna manhole is a suggested procedure for obtaining reliable communications.

119. Radiological Defense Equipment

Equipment such as the tactical dosimeter radiacmeter 1M–93/UD and technical self-reading dosimeters should be used in all radiation decontamination stations and their use is advisable within any personnel shelter. Disposable clothing, tape, and boots should be stored within any structure from which monitors will check surface radiation. Dose rate radiacmeters are required to confirm the safety of filtered incoming air, and to check for leakage around blast closures. Means by which an airtight seal can be formed about an entrance should be on hand within the structure and may be as simple as a large plastic film which may be tacked and taped about the entrance structure. A means of measuring radiation on the surface may be provided as shown in figure 123.

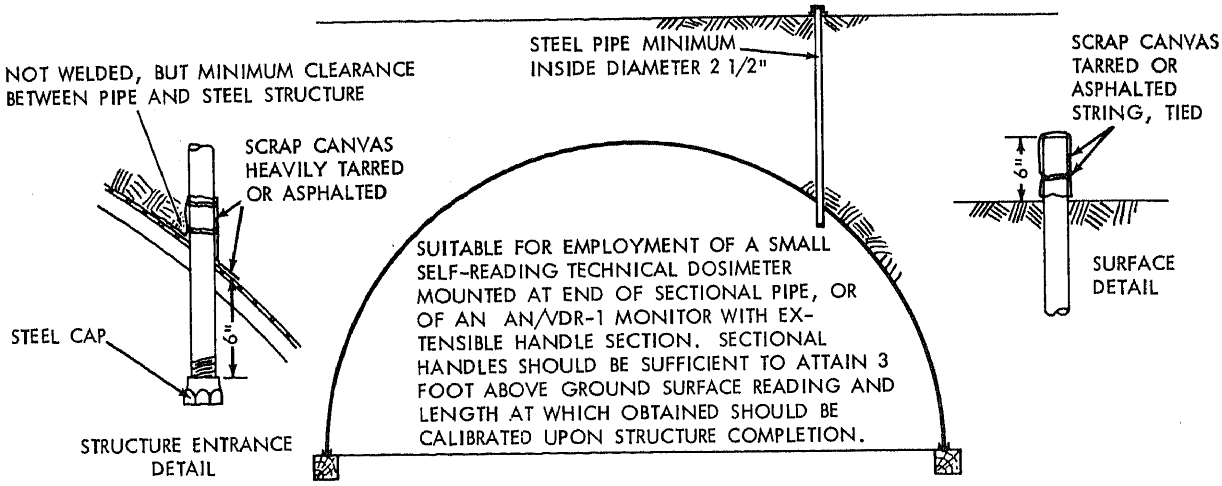


Figure 123. Surface radiation measurement (shown with a corrugated steel structure).

CHAPTER 6

DESIGN OF STRUCTURE

Section I. INTRODUCTION

120. Construction Considerations

a. Basis for Determining Type Structures.

(1) Nuclear weapons effects tests have proved the ability to provide blast-resistant protection, and have indicated how and to what pressure levels various types of structures undergo permanent deformation or collapse. The test results have been used as the principal design criteria for the structural and utility elements given in this manual. When no test results have been available, theory has been used as it was developed from nuclear test results or from dynamic or ultimate strength tests.

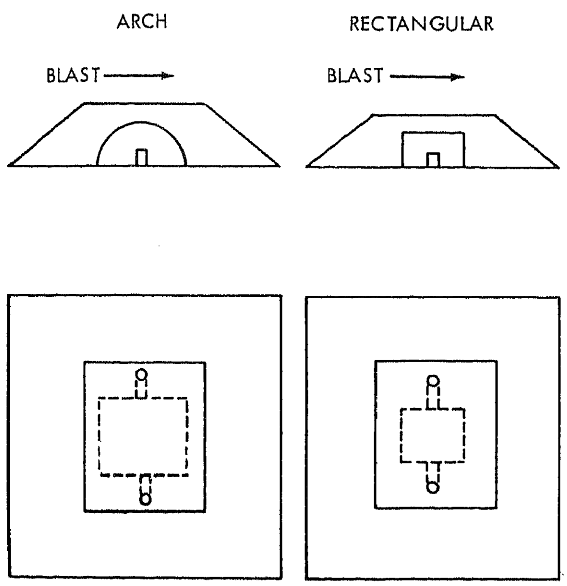


Figure 124. Orientation of structure to blast wave.

(2) In this manual, no designs are given for an aboveground structure because the reflected and drag pressures on the walls of such a structure prohibit its use. Also, effective radiation protection requires earth cover, which essentially prevents use of aboveground, uncovered personnel shelters. There are designs for semiburied structures, but such structures should be used only when unavoidable or for storage purposes. The desired orientation of a structure to the probable direction of blast wave is shown in figure 124.

b. Selection of Components. A shelter composed of basic structures and structure components can be erected by unskilled troop labor. Flexible steel structures are particularly recommended where good backfill conditions exist. Where subgrade and backfill conditions are poor, reinforced concrete conduits or other reinforced concrete structures should be used. Whenever feasible, large pieces of equipment, such as generators or filter units, should be placed in the shelter during construction to avoid awkward procedures and possibly allow the use of desirable smaller entrance sections.

c. Design Procedure. Test-proven resistance capacity is the principal criterion used here in design. Known modes of failure at overpressures of destructive magnitude are used to give the relative strengths of similar materials and to redesign structures known to be adequate for the 50-psi (3.5 kg/sq cm), side-on overpressure region. For example, a 12½-foot-radius, corrugated steel, arch structure has been tested under numerous conditions of overpressure and cover placement, including pressure of over 50 psi, without structural damage. This

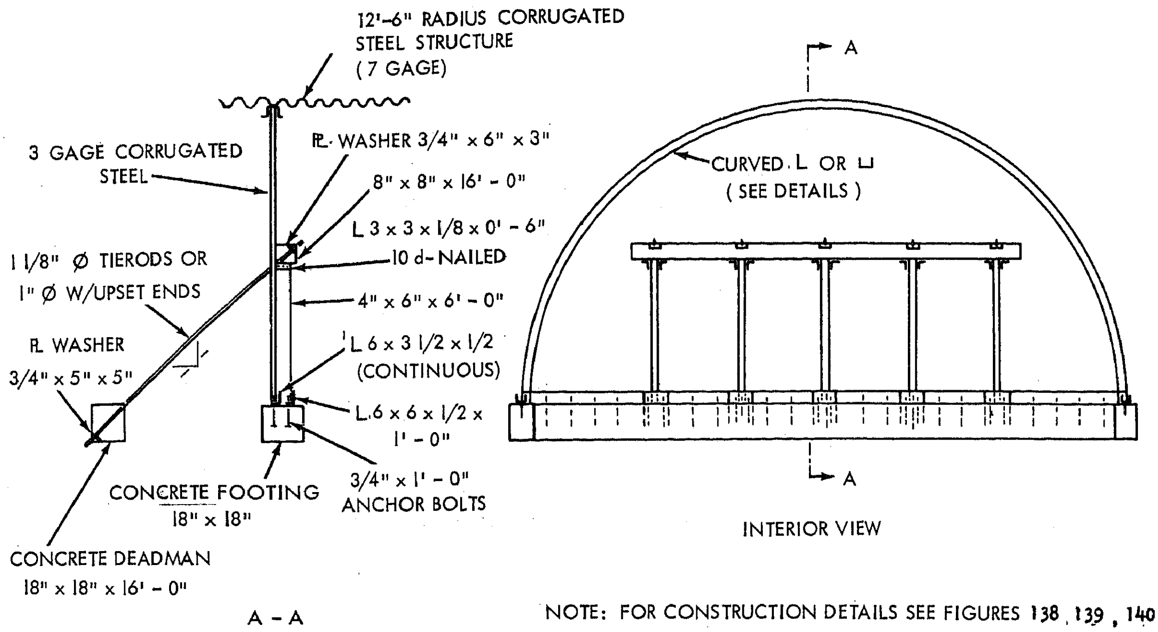


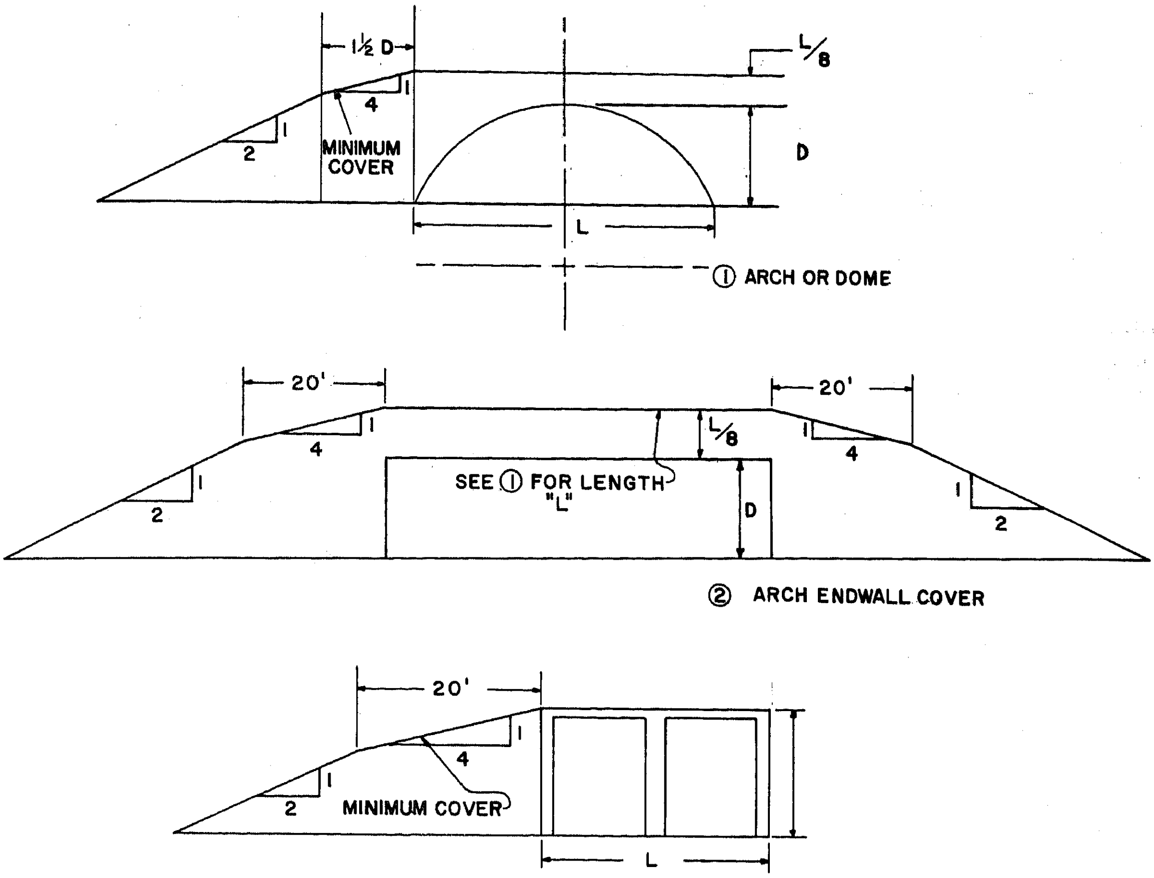
Figure 125. Structure-and-deadman-supported endwall suitable for 50 psi. Shown with 12½-foot radius structure.

represents the optimum structure shape and type material. In the tests, the endwall was integral with the end of the structure. The endwall was suitable for design overpressure, but at a higher overpressure (just below that required for collapse of the arch), deformation of the structure made it useless when the arch rib pulled away from the endwall and allowed an opening through which the soil could sift into the structure. This caused a large opening to the ground surface. Nuclear contamination (from fallout and induced soil activity) entered the structure with the result that it would not protect against additional blast loadings and fallout. The endwall was moved to a position within the structure as illustrated in figure 125. With the endwall in this position, permanent deformation may occur without creating an opening through which earth may sift into the structure.

121. Semiburied Structures

a. Example. The earth cover configuration shown in figure 126 should be used for all buried structures. This cover represents the minimum; more earth may be required for radiation protection. (See chapter 2 for more detailed information on radiation protection.)

b. Limitation of Semiburied Placement. Semiburied placements are not desirable. Their use should be limited to those situations where fully buried placements are not practical because of high water table, bedrock, or entrance requirements. However, if the semiburied placement cannot be avoided, primary consideration should be given to the corrugated steel arch for the overpressures considered in this manual. A secondary consideration may be the reinforced concrete arch. Rectangular structures on the other hand, are undesirable for semiburied placement. Paragraph 122 discusses the purpose of earth cover. The designs of the basic structures and components for semiburied use are taken up in section II of this chapter because, in general, the earth cover configuration is the only difference in design between the semiburied placement and the buried placement.



The illustrations on this sheet are the cover requirements for corrugated steel shelters in order that they respond as fully buried structures.

NOTE: The cover dimensions may have to be "increased" due to shielding against initial nuclear radiation. See section I, chapter 2.

Figure 126. Cover criteria.

Section II. CORRUGATED STEEL BURIED STRUCTURES

122. Structures and Components

a. Types. The types of structures and structural components are illustrated and discussed in detail in this section, with particular regard to their design and employment. The components are assembled, together with utilities to form the overall protective structure design. This procedure is outlined in the design of sample structures in chapter 7.

b. Depth of Burial. The structures are to be fully buried or are to use the berms described in paragraph 130*b*. A semiburied circular or arch basic structure must use a berm at the end of the structure selected as if for a rectangular structure of the same height, width, and burial condition as that of the endwall (figs. 126 and 127).

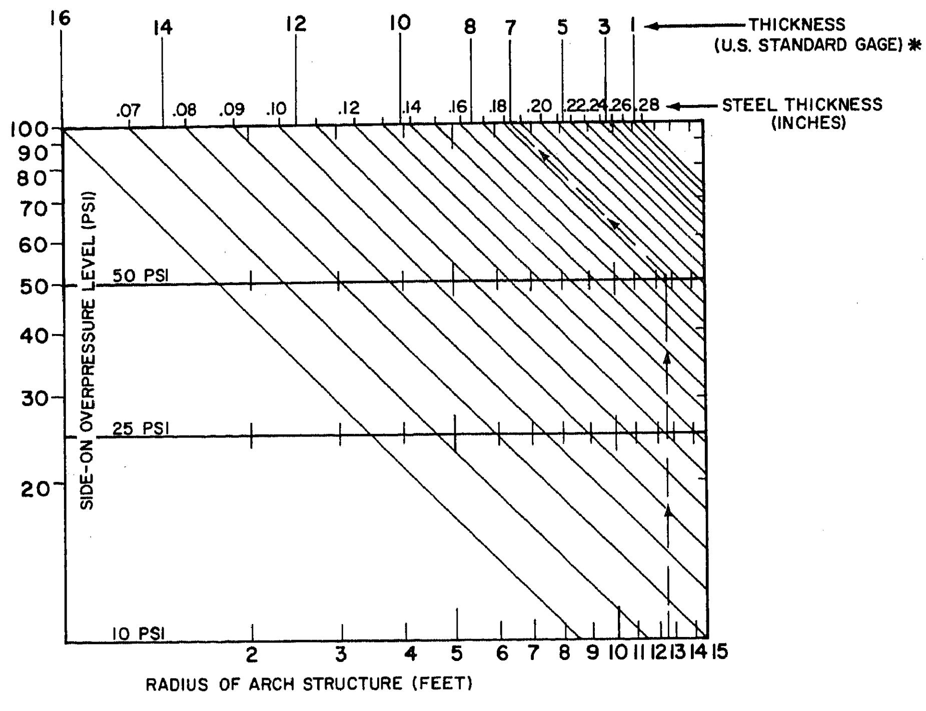
c. Means of Selection. Components of the structures are, in most cases, selected independently from other component groups, with some obvious exceptions that certain combinations of entrances, doors and frames, and frame foundations are impractical. Chapter 7 explains how structures and components are selected to provide a complete design for a specific use.

123. Circular Corrugated Steel

a. Corrugated Steel Arch. Corrugated steel arch and circular shapes have undergone numerous successful tests under nuclear blast overpressures both as underground horizontal passage and shelter structures and as a vertical tube providing an entrance from ground shelter to the structure. A requirement in the employment of corrugated steel is the avoidance of longitudinal thrust from endwalls and bearing foundations of blast closures. The curved steel section is the most efficient section for uniform loads applied radially or tangentially. An appropriate berm provides such loading for a semiburied horizontal structure or entrance when used with adequate backfill control.

b. Curved Corrugated Steel. Curved corrugated steel sections are produced in nestable sections with flange joints in diameters up to 7 feet (2 m) and with bolted lapped joints in diameters up to 30 feet (9 m). The performance of such pipe and the computed ultimate strength of the assembled section have been used to derive figure 127, which presents the required gage for pipe used in buried structure and entranceways.

c. Design of Buried Corrugated Steel Arch. The design of the buried corrugated steel arch and circular structures is based upon the mode of failure of such arch structures when subjected to uniform blast pressure on the ground surface. The basis of the design of the berms described in paragraph 130*b* was based on such arch structure placed aboveground and exposed at incident peak overpressure ranges of 60 to 200 psi (4 to 14 kg/sq cm). The structures responded in the compressive mode and the steel plate failed in bearing and shearing of the bolts at longitudinal seams.



Example: Gage for 12½-foot radius arch in 50 psi overpressure region.

Minimum thickness 0.182 inch, use 7 gage

Note: 1. Entrance sections within three feet of the surface should be selected, using 2 x design overpressure.

Example: In 50 psi overpressure region, select such section of the entrance using 100 psi design

*2. Assumes a flanged joint or lapped joint with 4, 3/4" ø bolts per foot of longitudinal seam.

Figure 127. Corrugated steel gage selection for circular and arch structures.

d. Design Chart. Figure 127, which gives the gage selection for design, was derived directly from the same strength tests and the linear variation of stress with radius. The use of the computed ultimate strength for design for blast overpressures is justified by nuclear test results. The validity of the design chart was checked by comparing the overpressures at which such structures have failed and those which the structures have withstood, with the overpressures allowed for sections of the same gage and radius by the chart. Test results have not been of such quantity that precise failure overpressures can be identified, but these pressures have been bracketed for certain gages of steel and radii and have indicated that overpressure approximately twice that allowed would be required to cause complete collapse.

STANDARD SIZES 2" x 6" (PITCH) CORRUGATED STEEL CATTLE PASS SECTION

SPAN	RISE	GAGE AVAILABLE (U.S.S.G.)
5' - 8"	5' - 9"	12, 10, 8
5' - 8"	6' - 1"	12, 10, 8
5' - 9"	6' - 6"	12, 10, 8
5' - 9"	7' - 0"	12, 10, 8, 7
5' - 9"	7' - 4"	12, 10, 8, 7
5' - 10"	7' - 10"	12, 10, 8, 7
5' - 10"	8' - 2"	12, 10, 8, 7

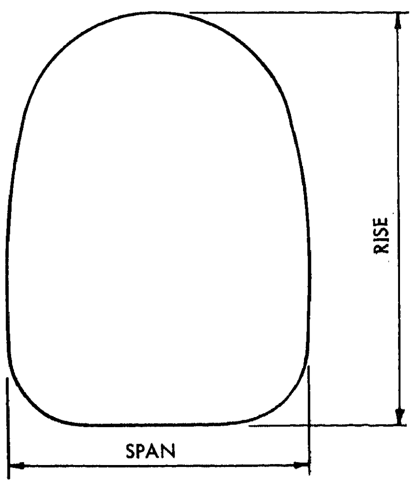


Figure 128. Sectional plate underpass.

e. Variation. A variation is the 2" x 6" (pitch) sectional corrugated plate which is used conventionally as a pedestrian underpass or as a cattle pass. This may be employed for horizontal passage configurations. A sample cross section of this underpass is shown in figure 128. Figure 127 may be used for selection of the gage steel required for a given design overpressure by taking as the radius one-half the span. Structures of 7'–10" (2.4 m) rise, 10-gage steel when buried have withstood nuclear blast surface overpressures of up to 153 psi (1077 kg/sq cm) without significant damage.

124. Design of Steel Arch

The design of the steel arch structure employs the steel gage and assembly described above. Variation occurs in the provision of a footing for bearing of the structure. Response of the structure is such that there is little benefit from tied arch or end fixity. The footing is consequently designed to withstand the static earth load and differential settlement under blast loadings. The occurrence of permanent settlement under such loadings actually lengthens the response time and increases the dynamic capacity of the structure so far as the steel plate continues to respond as an integral

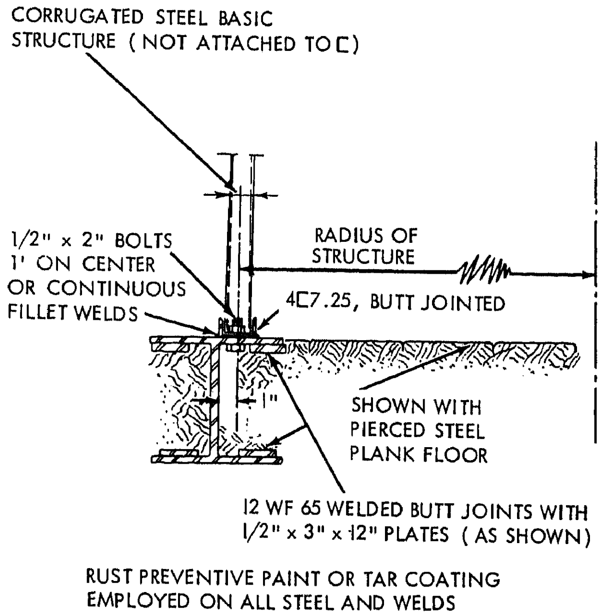


Figure 129. Structural steel footings for corrugated steel arch structure.

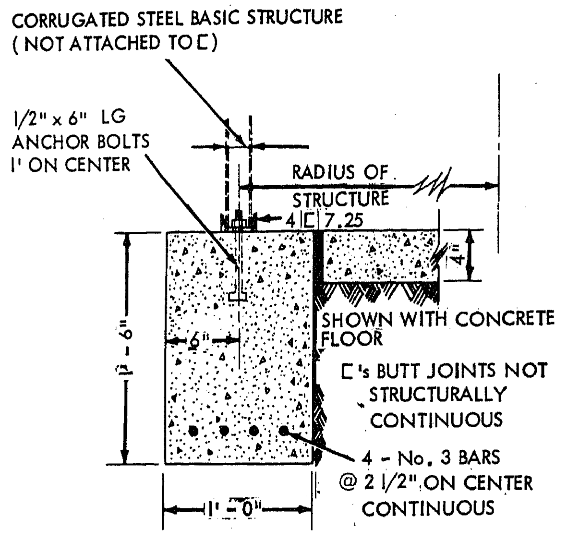


Figure 130. Concrete footings for corrugated steel arch structures suitable for up to 15-foot radius, 50-psi side-on overpressure.

flexible arch. Footing designs for structures of varying span are given in figures 129 through 131.

125. Footings

The designs of the footings illustrated in figures 129 through 131 have been tested at a wide range of overpressure and structure spans. The footing designs provide adequate bearing areas for minimum settlement of the structure under static loads. However, permanent settlement will occur when the structure receives a blast loading. There are no structural ties at the junction between the footing and the floor. By allowing the footing to punch into the soil until sufficient reaction forces are developed, the energy absorbing capacity of the total structure is increased. To assemble the structural plate section easily, the 4″ C 7.25 (4-inch channel, weighing 7.25 pounds per running foot) base channels must be absolutely parallel with each other. Grout can be placed between the channel and footing to shim each side into vertical alinement.

a. Timber. Of the three designs shown (figs. 129 through 131), timber is the most suitable for field use. It is a readily worked material and requires no curing or other time delays inherent in concrete construction. Timber footings should be petroleum base treated or have a heavy coat of asphalt or tar.

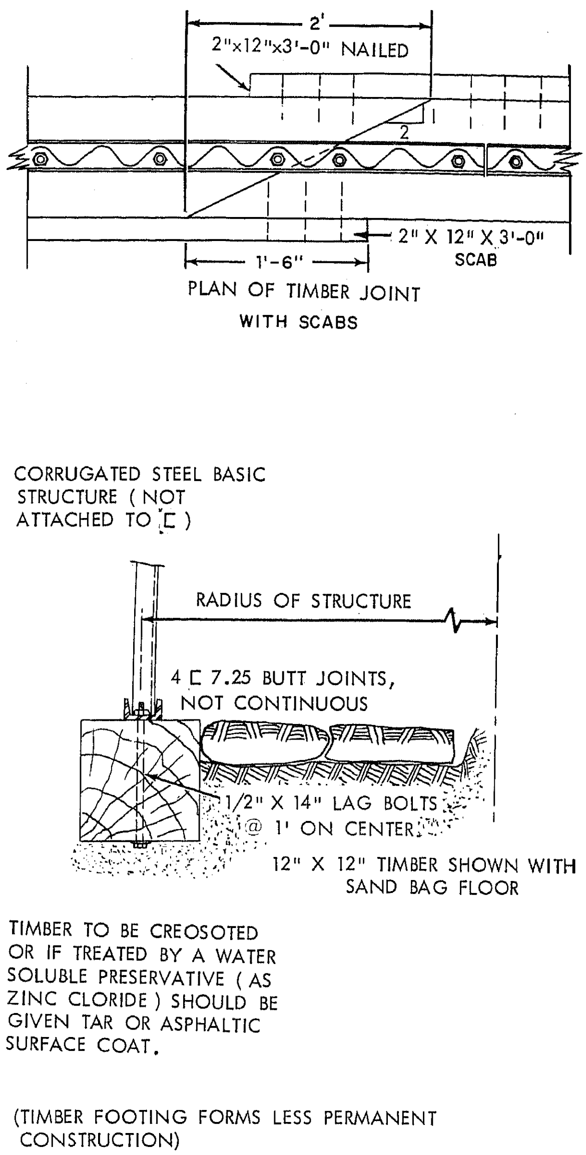


Figure 131. Timber footings for corrugated steel arch structures.

b. Steel. A 12 WF 65 steel beam can be used to form a continuous footing for the structure. This steel section has a greater flectional strength than required so a flange width is provided for sufficient bearing area. Substitution of a lighter steel section should be made on the basis of maintaining a steel thickness not subject to adverse weathering effects and provid-

ing adequate bearing and depth (1 foot depth (0.3 m) is considered minimum).

c. Concrete. A lightly reinforced concrete footing forms an excellent structure foundation. The 18-inch (0.46 m) depth by 12-inch (0.3 m) width cross-section will accept the largest span structure.

Note. There are no steel ties between the footing and the floor slab. A mastic joint allows the two components to displace independently.

126. Floors

a. Soil. Well-graded and compacted soil forms a floor which is least apt to be affected by overpressure or blast effects. A well graded sand or gravel, possibly with the use of a stabilizing agent, would be in this category but might have some undesirable features. A soil floor should be of the same quality material as that required for backfill. Calcium chloride or a similar moisture-absorbing agent may be used in small amount to prevent dusting of the surface. Gravel or sand should not be used in entrance configurations or near blast closures where there would be possibilities of granular material being transported by overpressure leaking past the closure (missile hazard) or of the gravel clogging the seal and preventing functioning of the closure device. Lightweight rail equipment employing rail and the tie units may be used with an earth floor to provide heavy haulage facilities and retain the advantages of earth flooring. Sandbags may be used when a poor soil would otherwise be exposed, such as a clay or silt (fig. 131).

b. Sectional Wood Flooring. When a solid floor is needed to support equipment or to meet

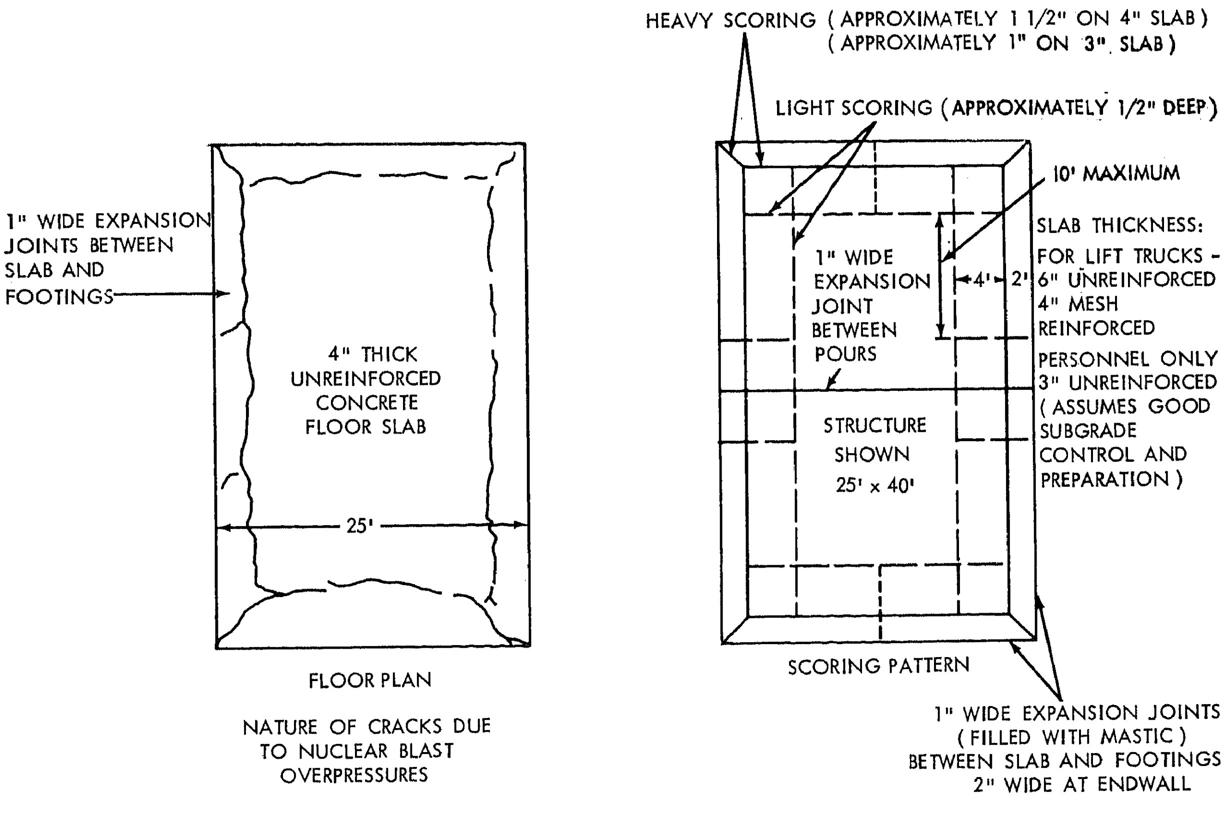


Figure 132. Concrete floor.

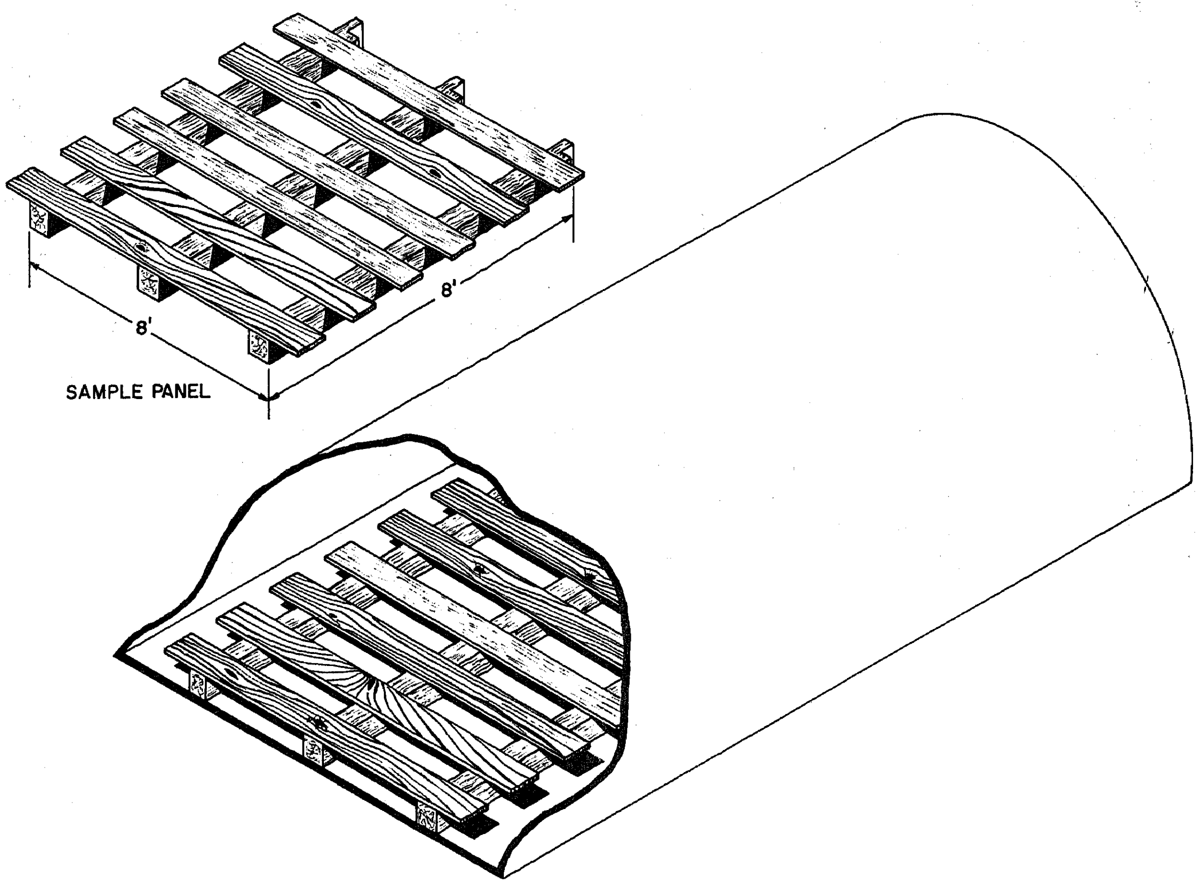


Figure 133. Duck boards.

the needs of structural use and occupancy, sectional wood flooring makes a floor well suited to giving with the heave or settlement of nuclear blast effects. This flooring, essentially the same as employed for tests, uses a wood sheathing wearing surface held by a 2- x 4-inch (51 x 101.6 mm) frame. The upper limit on dimensions of the sections should be held to 8 feet (2.4 m) to provide a section which may be readily handled, moved, and replaced on the bearing soil. The flooring thickness and the size and spacing of the supporting cross members are solely determined by the use of the structure. The flexibility gained by the use of sections not rigidly joined and providing room for inward displacement of the basic structure's sides furnishes the resistance to damaging effects of the nuclear blast overpressures. Variations on this type flooring would be the employment of pallets or flooring sections placed only on those portions of the underlying earth floor where specifically required. Figure 133 shows a wood floor.

c. Pierced Steel Plank. Pierced steel or aluminum plank may be used to form a flexible yet heavy duty wearing surface (fig. 129). When used to provide covering for an entire floor surface, the plank should be laid parallel to the major axis of the structure, as earth heave or settlement due to blast loadings on the structure generally parallels the footings.

d. Concrete. A poured-in-place concrete floor provides an excellent, clean wearing surface which may be designed to withstand heavy loads and the adverse effects of nuclear blast overpressures on the structure. The thickness of the concrete floor and subgrade should be de-

signed on the same basis as any other floor slab. The reinforcement, if any, should be added to carry the loads on the slab. Unreinforced concrete floor slabs ($f'_c = 4{,}000$ psi or 281 kg/sq cm) poured on compacted earth subgrade have been tested in flexible metal arch structures in side-on overpressure regions of up to 100 psi (7 kg/sq cm). Under such nuclear test, cracks were caused in the concrete as shown in figure 132. The possibly adverse effect of such cracking under footing settlement and floor heave could be avoided by the use of scoring and expansion joints as illustrated in figure 132. Eight hundred square feet (74 sq cm) is considered a maximum for a single slab. Such a slab should have heavy scoring as illustrated. Figure 130 includes an example of a concrete floor.

127. Endwalls

a. Deadman Supported. An endwall should be designed that is compatible with the blast resistance of the basic structure. The basic structure should not be weakened by force imposed by the endwall. A practical solution to these requirements is an endwall that acts independently of the basic structure, yet that prevents earth infiltration under permanent deformation of the endwall. The principal employment of such an endwall would be with the corrugated steel arch structures. The design of the endwall, as illustrated in figures 134 through 137, employs a deadman for the restraint, a frame transferring the load to the deadman, and a sheathing to hold the earth-

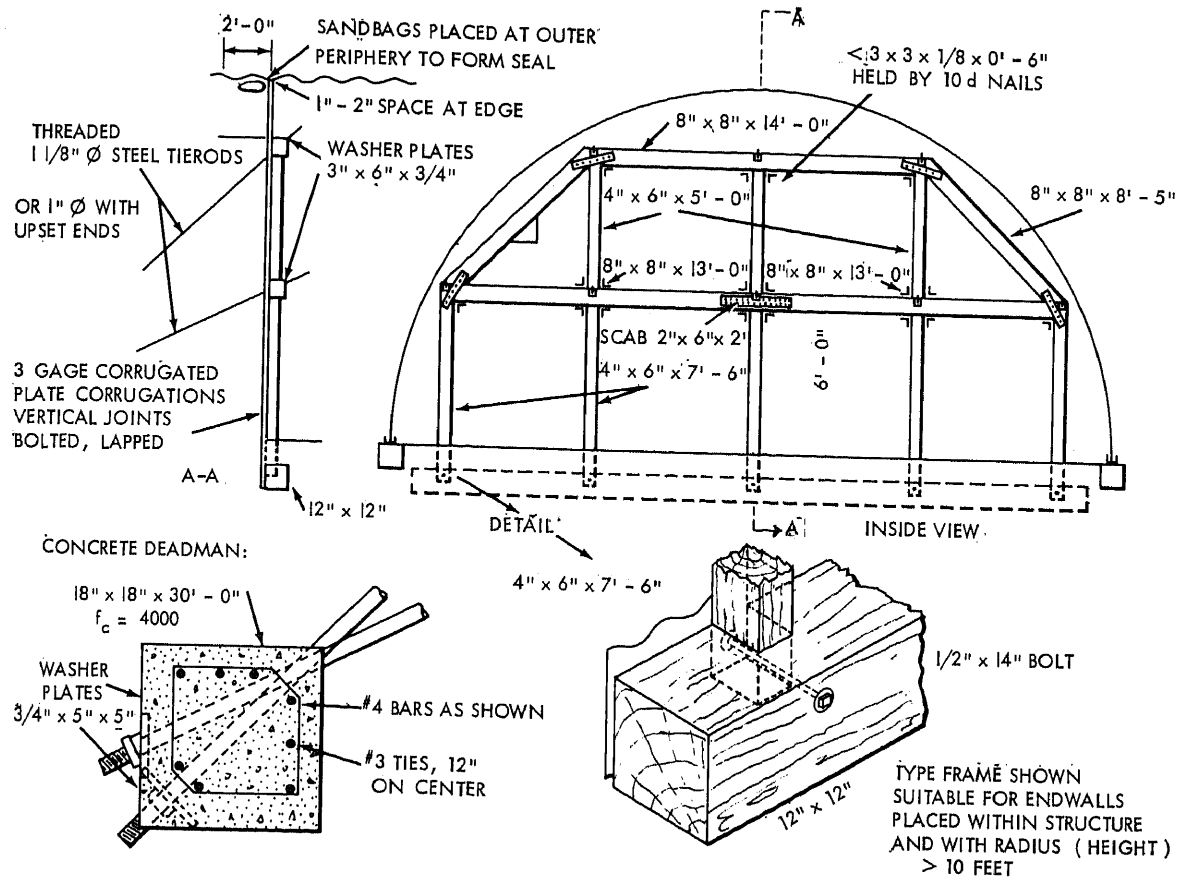


Figure 134. Framing plan of timber-framed corrugated steel endwall suitable for 50 psi. Shown with 15-foot-radius structure.

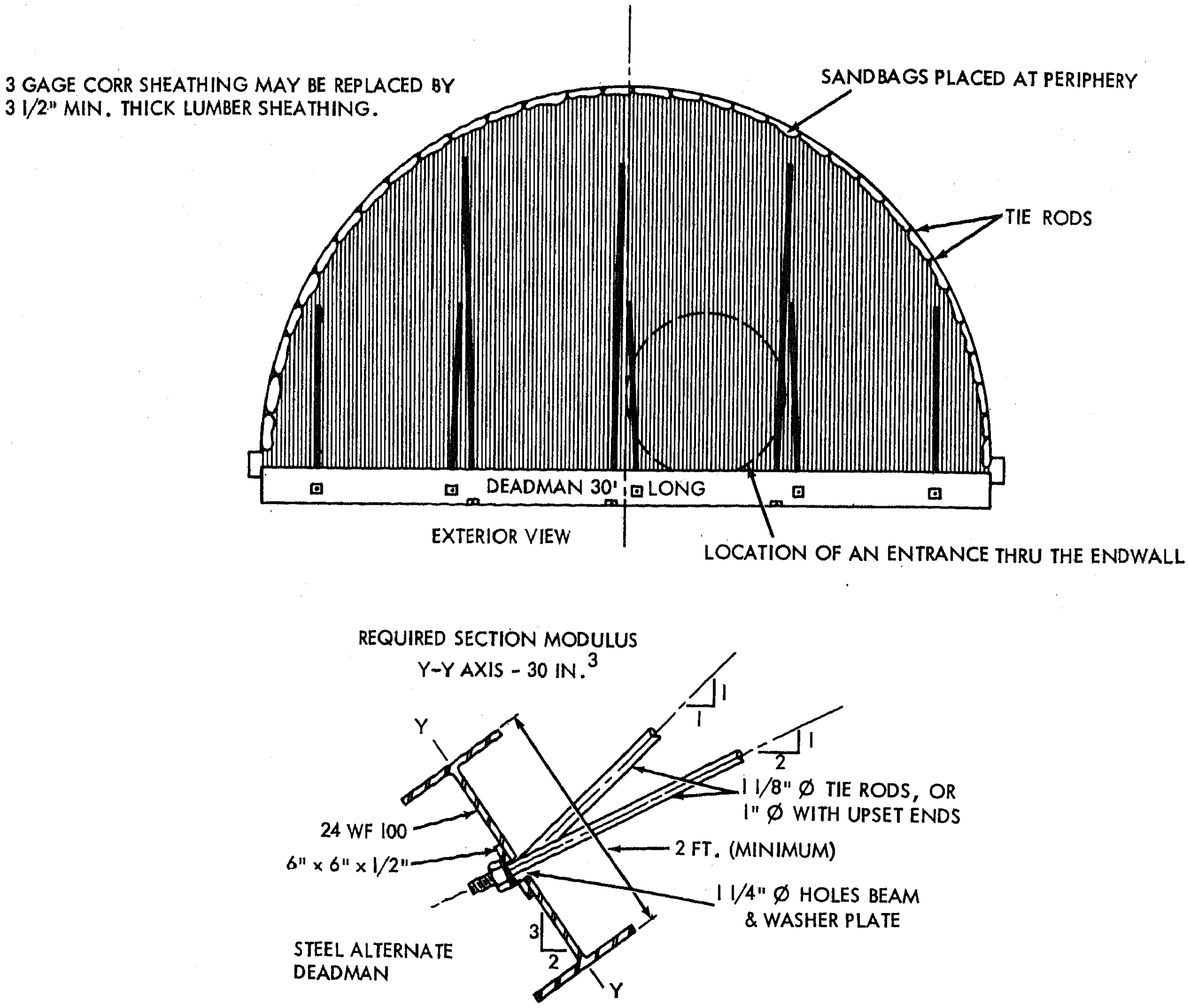


Figure 135. Exterior view of timber-framed, corrugated steel endwall suitable for 50 psi. Shown with 15-foot-radius structure.

transmitted pressures. As shown in figures 134 through 137 various materials may be used for the sheathing, the frame, and the deadman. Endwalls of similar construction and materials have withstood surface side-on overpressures of up to 100 psi (7 kg/sq m) from nuclear tests. It is essential that the empirical results of the nuclear tests be used in the design for endwall restraint, as these tests have shown that the capacities of deadmen under such loading far exceed those computed from static procedures.

b. Structure- Deadman-Supported Endwall. Flexible steel structures of small radius or height and reinforced-concrete culvert sections may effectively employ endwalls which bear longitudinally upon the basic structure without materially reducing the structure strength. Such endwalls may be of reinforced concrete, timber, or corrugated steel. Corrugated steel or wood sheathing endwalls in general require a steel or timber framing, and wide spans of timber may require framing. Endwalls representing all of the above types have successfully withstood surface side-on overpressures of over 100 psi (7 kg/sq cm) in nuclear test series. These empirical results have been used to design endwalls illustrated in figures 125, 134 to

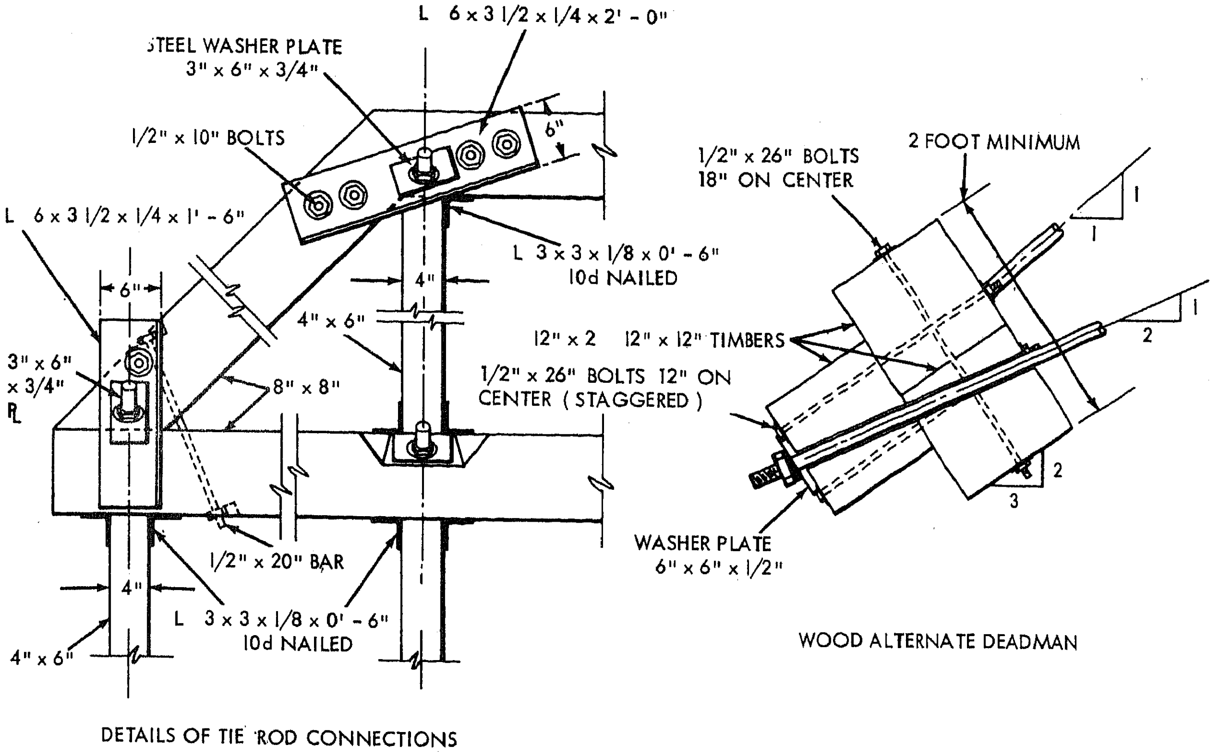


Figure 136. Connection details of timber-framed, corrugated steel endwall suitable for 50 psi. Shown with 15-foot-radius structure.

137, and 149. The endwall in figure 149 employed with a circular concrete culvert structure may be used with identical placement and bracing for corrugated steel circular and cattle-pass sections of 8-foot (2.4 m) diameter. Table XXIX gives allowable dimensions for various spans. The endwall shown in figure 137 for structures with 10 feet (3 m) or less radius may be used as a structure-supported endwall with similar bracing configuration, sheathing, deadmen, footings, and tie rods for structures with a radius of 13 feet (4 m) or greater. Corrugated steel structures of 12½-foot (3.8 m) radius have been thoroughly tested, employing structure-bearing endwalls—timber framed deadman supported—as shown in figure 125. Other details are given in figures 138 and 139 for deadman-supported endwalls.

c. Earth at Angle of Repose. Basic structures with low height and certain entrance configurations may advantageously employ an endwall which consists of compacted earth placed at its angle of repose. This type of endwall has the advantages of providing a means of entrance to the structure essentially free of shear and differential settlement forces and of avoiding the use of a constructed endwall. Disadvantages are the undesirability of an open earth face and the requirement for a much longer basic structure to provide required floor space. The earth endwall has not been tested under overpressures from nuclear detonations, but its use would avoid some of the adverse structural effects the rigid endwalls have had on respond-

Table XXIX. Wood Endwalls.

Maximum unsupported span (ft.)	Suitable beams nominal size (in.)
4	2 x 8, 3x 8, 4x 8, 6 x 8
5	6 x 8, 8 x 8, 10 x 10
6	6 x 10, 8 x 10, 10 x 10, 12 x 12
8	6 x 14, 8 x 14, 10 x 12, 12 x 12
10	6 x 16, 8 x 16, 10 x 16

Note. For use with culverts and cattle-pass sections.

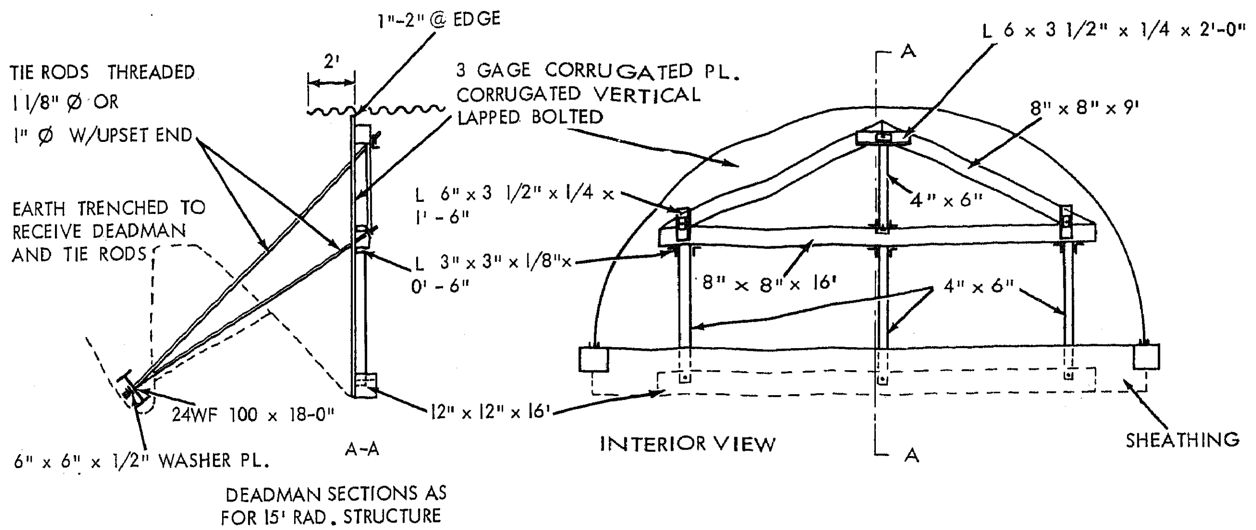


Figure 137. Timber-framed, corrugated steel endwall suitable for 50 psi. Shown with 10-foot-radius structure.

ing basic structures in such tests. The endwall is designed in the field by determining the angle of repose of the earth to be employed when that earth is dry. This slope is used for the endwall, even though batting or sandbags may be needed to provide a dry wearing surface. The top of the earth fill must be inside of the end of the structure a minimum of 2 feet (0.6 m). Employment of this type of endwall is shown in figure 141. This type of endwall may be used only for fully buried structures.

128. Entranceways

a. Types. Extremely high reflected pressures are developed upon surfaces that obstruct the passage of the shock wave, as may be noted in figure 12. The use of entrances that have closures flush with a horizontal ground surface essentially avoids the development of pressures greater than that of the side-on overpressure. Similarly, such entrances may employ underground passage sections which need not be designed for high reflected pressures. In certain instances the use of a horizontal entrance from the ground surface cannot be avoided. Under such circumstances, a passage section should be employed whereby the basic structure may have sufficient earth berm on all sides to achieve fully buried conditions. The use of vertical shafts and lifting equipment should be thoroughly considered before using any vertical closure and horizontal passage. Personnel shelters should use two blast closures to prevent the loss of all occupants and contents which would if as design overpressure arrived at the structure site when the blast closure was open. Single closures should be employed only on nonpersonnel structures or with the calculated risk of loss and casualty. The employment of two personnel blast closures, in effect forming an air lock, will require an operating or signal procedure in order to insure that at least one door is closed at all times. Both closures must be designed for full blast overpressure. The air lock could be used as a decontamination chamber.

b. Vertical Tube to Horizontal Passage. Op-

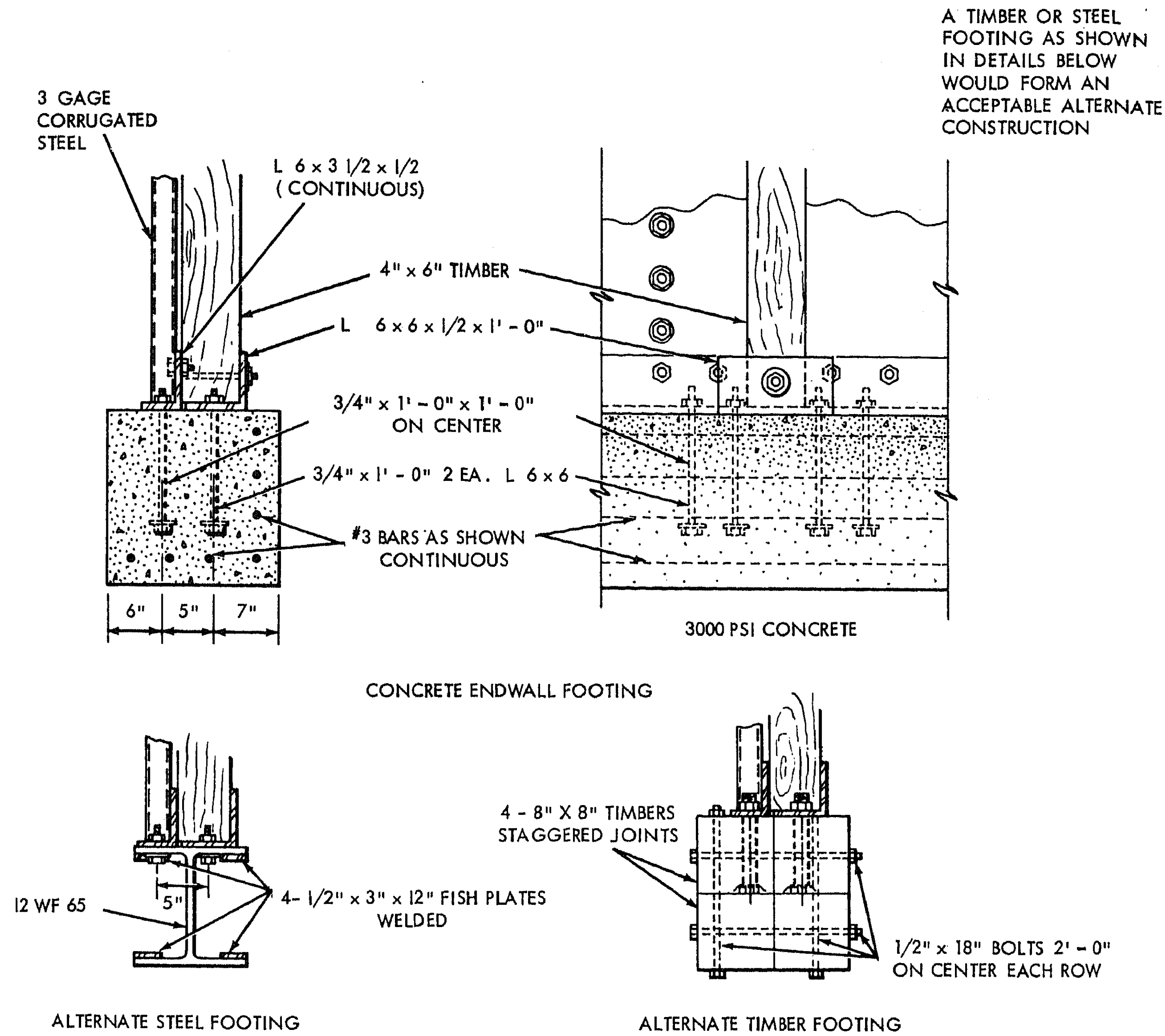


Figure 138. Structure- and deadman-supported endwall suitable for 50 psi. Footing details.

timum resistance to nuclear blast effects is gained by using a flush-with-the-ground surface blast closure and a small diameter vertical tube passage to a fully buried horizontal circular passage. Such entrance configurations have been tested at over 150-psi (10.5 kg/sq cm) side-on overpressure without damage. The configuration shown in figure 141 combines these optimum features with a transition between vertical and horizontal passage that permits rapid entry or exit. The dimensions of the illustrated configuration are examples and may be varied to permit additional use of the horizontal section, or the passage of larger items through the vertical tube. Variations from the illustrated section may be made by the substitution of circular prefabricated concrete sections for either section or by the use of a cattle pass conduit section for the horizontal section. Selection of endwall for the horizontal section should be as described for the basic structure in paragraphs 120 and 121.

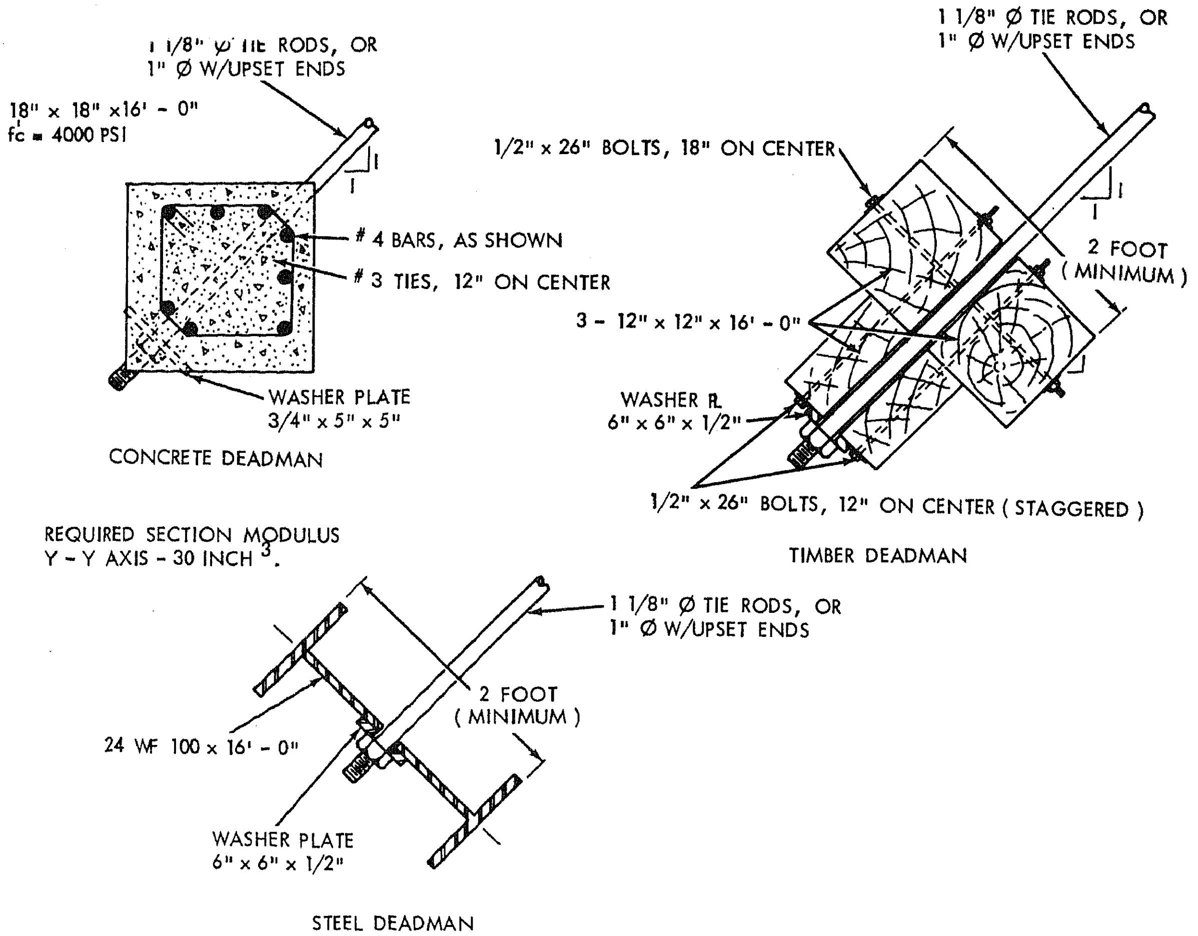


Figure 139. Structure- and deadman-supported endwall suitable for 50 psi. Deadman details.

c. Offset Personnel Entrance. The offset personnel entrance is an excellent choice for personnel entry. There are two basic reasons for this. First, a vertical shaft is the best blast resistant means of providing entry to a protective structure. Second, each 90° turn in an entrance configuration reduces the gamma radiation by a factor of 0.07. The configuration has a few drawbacks, among which is that it does not lend itself to the passage of bulky equipment. Construction is quite similar to that of a vertical shaft to a horizontal passage. However, it is well to note that there are no structural connections between the vertical and horizontal members. A canvas, or similar flashing material, well tarred or asphalted, forms the seal at each junction. The illustrated configuration is an example (fig. 142). Dimensions may be varied to permit additional use of the horizontal section, *for example,* as an equipment, storage, or decontamination room, or to allow passage of larger items through the vertical tube.

d. Filled Tube Emergency Exit. Any structure may be provided a blastproof emergency exit by the use of a corrugated pipe filled with sand (fig. 143). Such installations have been tested with success at high nuclear blast overpressures. This emergency exit provides a means of escape without requiring full-scale excavation. Personnel trapped by partial fail-

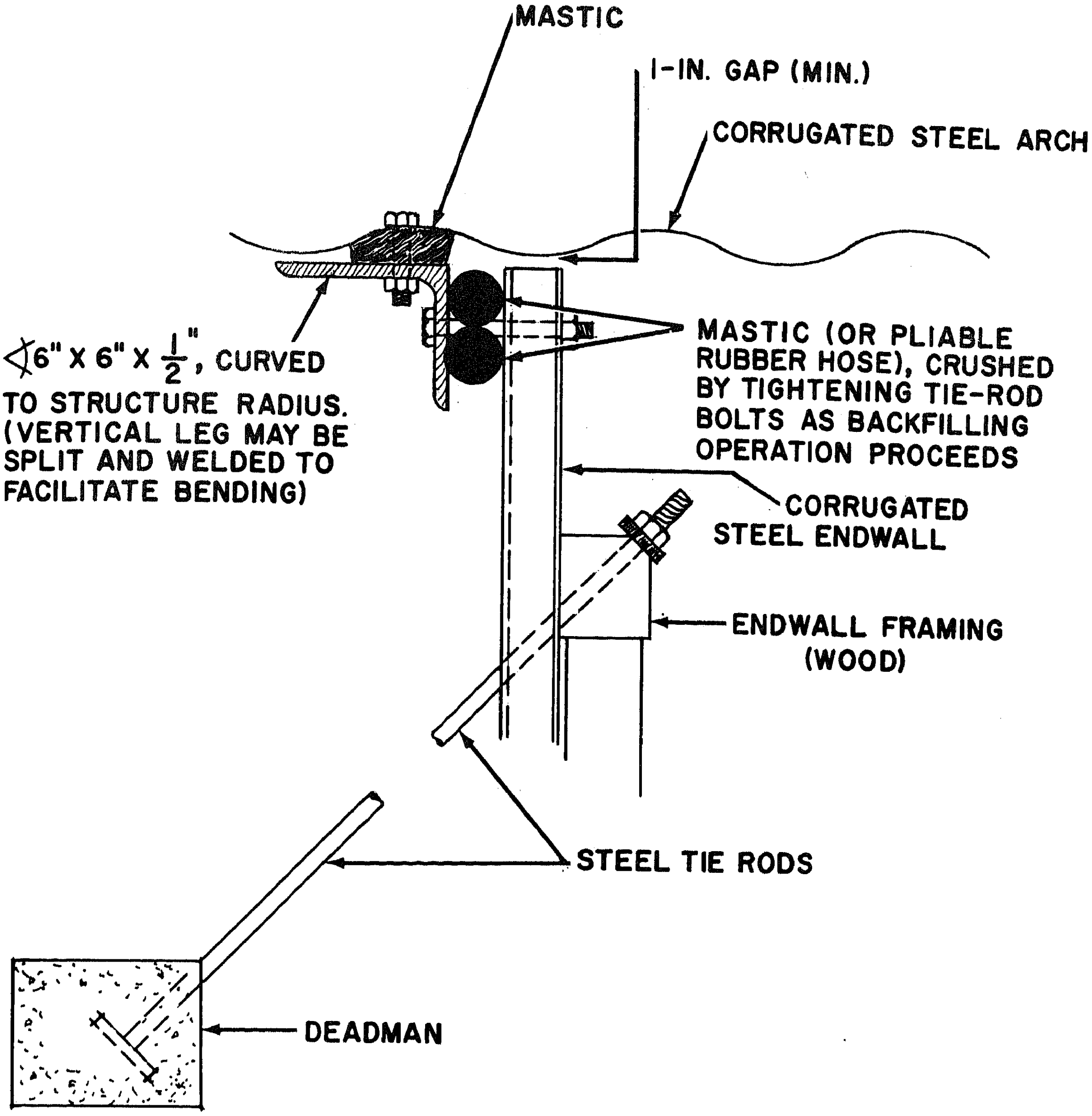


Figure 140. Structure- and deadman-supported endwall suitable for 50 psi. Connection details.

ure of the principal entrance, *for example,* by jamming or blocking of the closure way, escape from the structure with some effort. The sand is shoveled from the lower end of the emergency exit to permit gravity evacuation of the column of sand. Care should be taken in the selection of the fill material to prevent packing within the column which would hinder removal. Also, silty fines could foul the air within the shelter during the removal operation. The cross-sectional area and length should be kept to a minimum to reduce the amount of material to be removed. A ladder or steps should be placed within the pipe to insure exit, to avoid the need to store a ladder in the shelter, and to provide a means of access to material stuck in the tube during evacuation. The thickness of the corrugated steel is not critical

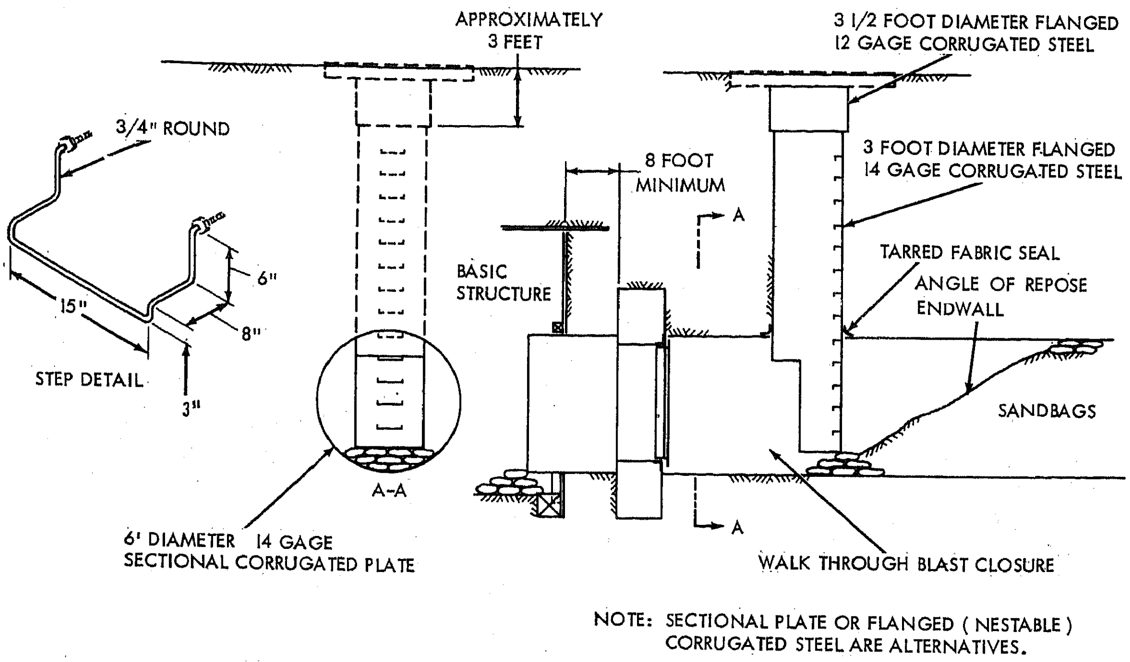


Figure 141. Vertical tube to horizontal passage, with intermediate backup blast closure.

if the fill material is well tamped. Therefore, the lightest gage available may be used. A frangible, waterproof cover may be placed over the exterior end of the exit.

129. Door Hatches

a. Requirements. The orientation of blast-resistant doors is critical in determination of the required design overpressure. For example, in a 50-psi (3.5 kg/sq cm) side-on overpressure region a vertical exposed face may receive 200 psi (14 kg/sq cm) as the shock wave is reflected, while a horizontal face flush with a level ground surface need be designed only for a 50-psi dynamic load is it is of short span. Exposed blast closures are one of the principal sources of radiation within a structure. Openings which may be created by a deformed or loose-fitting closure and the air supply system are the main sources of postshot contamination. The source of radiation within the structure is reduced most effectively by the use of small blast closures, by small diameter passages, and by offset or otherwise bent entrance configurations. Increasing the thickness of the blast closure does not form a satisfactory shielding solution. Closures presented in this section are designed solely for overpressure resistance. Those for flush placement over a vertical entrance or backup of such a closure have been designed for 50-psi (3.5 kg/sq cm) overpressure. The walkthrough, or drivethrough, closures and their in-tunnel closures and their in-tunnel backup closures have been designed for 200-psi (14 kg/sq cm) reflected pressure. Where possible, designs have been employed which have been proven satisfactory by nuclear blast tests upon similar or identical closures. These tests have shown that adequate closures for blast resistance are feasible. As may be noted from the presented designs, the span of the closure and its orientation are extremely critical. Means of reducing the required span or overpressure (as by use of a vertical shaft) should be thoroughly examined. Consideration should be given to possible disassembly of bulky equipment, or placement of such equipment during construction.

b. Designed Personnel Hatch. The optimum blast closure is a small-span hatch for vertical personnel entrance. Such a closure is used with the entrance configurations already described. A designed hatch, similar to one proof-tested

during nuclear blast tests and employing standard structural shapes and steel plate, is illustrated in figure 144. The steel sections shown may be varied provided that the section moduli of the substituted shapes are not less than those shown and the steel used meets ASTM A-7 standards.

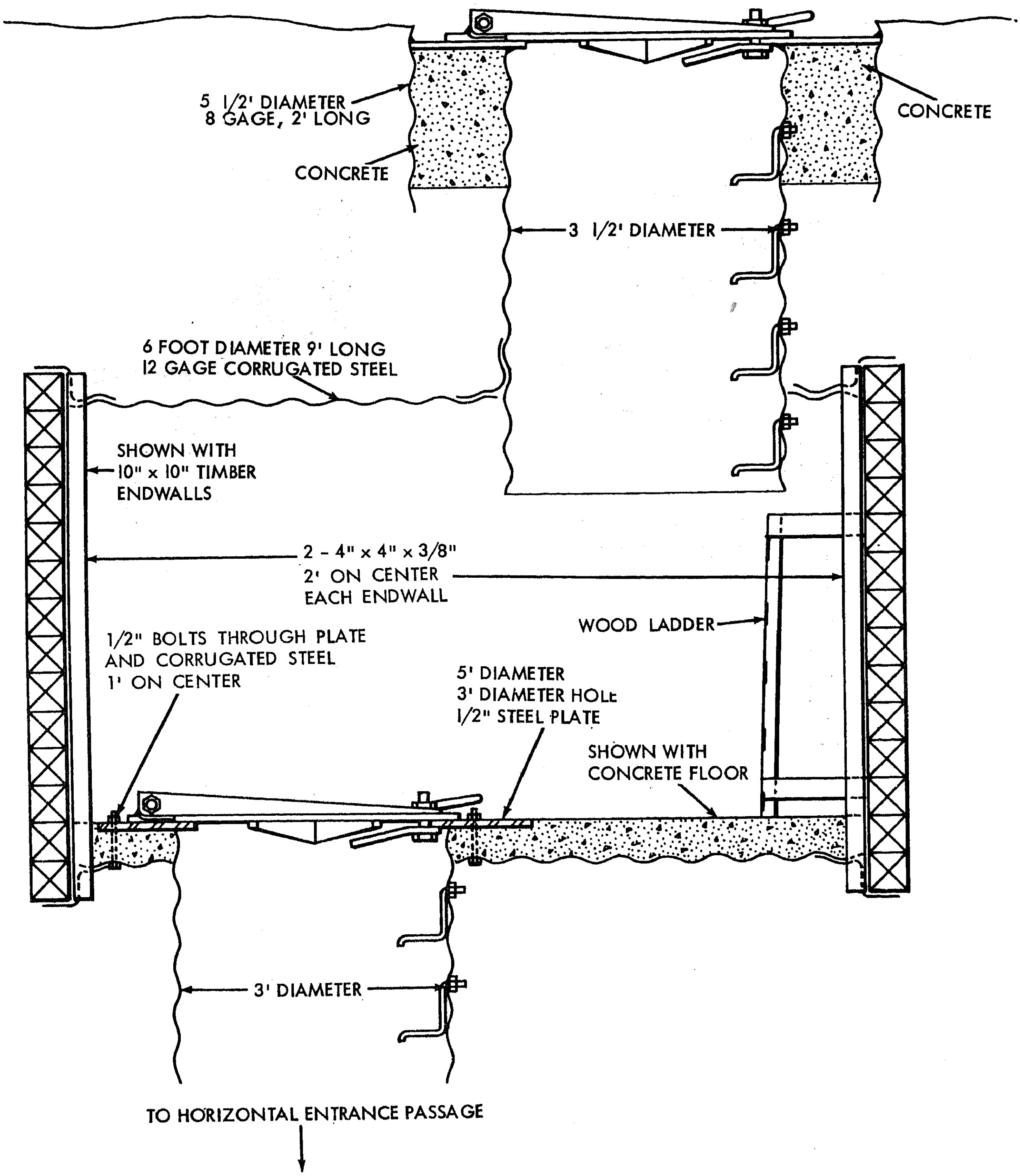


Figure 142. Air-lock personnel hatch installations.

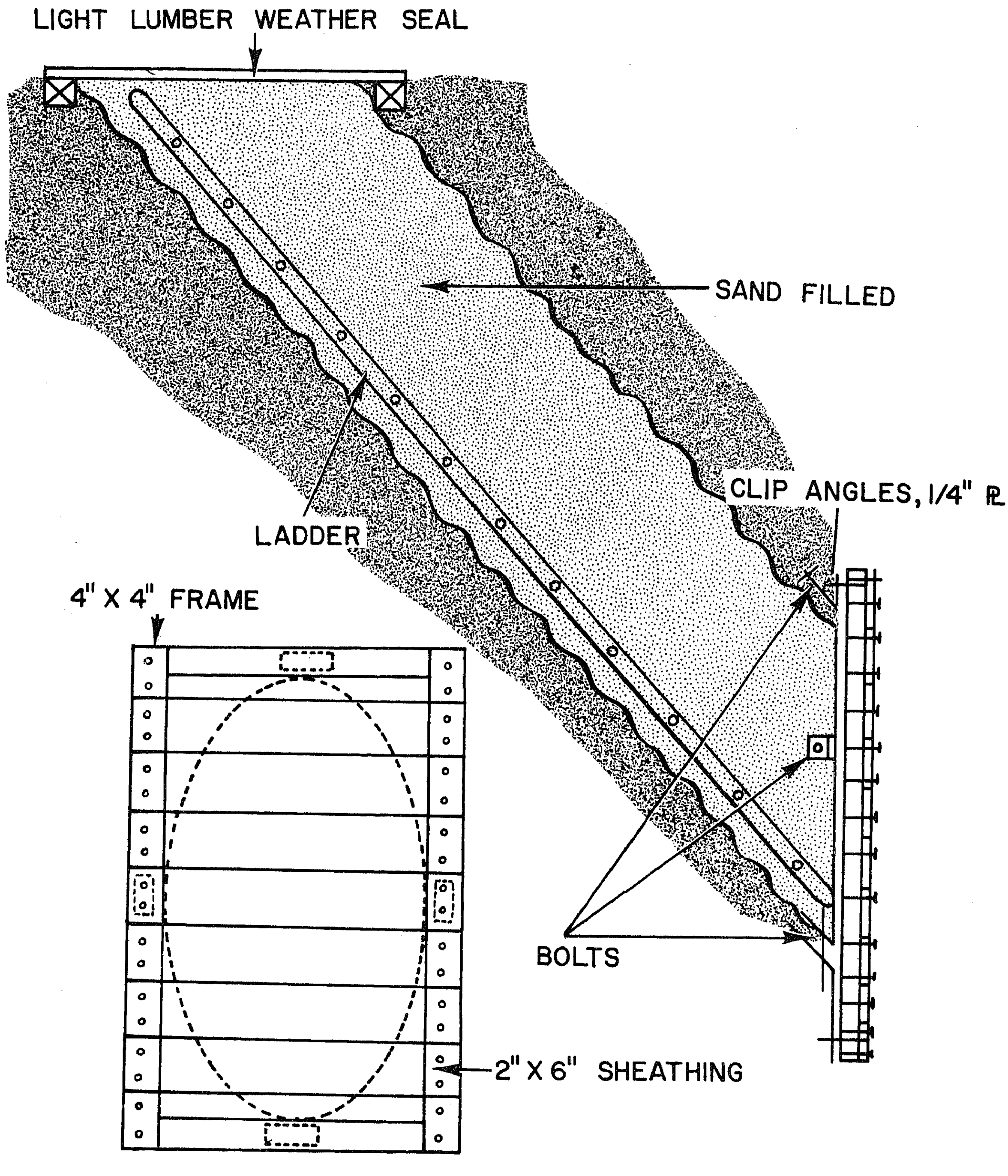


Figure 143. Corrugated steel emergency exit.

c. Uses of Personnel Hatch. The designed personnel hatch shown in figure 147 has been tested at side-on overpressures of up to 100 psi (7 kg/sq cm) without damage and provides a relatively lightweight, easily operated hatch. A personnel hatch should be employed for use at the surface and as a backup closure. In the latter application, installation may be for vertical passage as in figure 142 or for horizontal passage. In horizontal placement, the closure

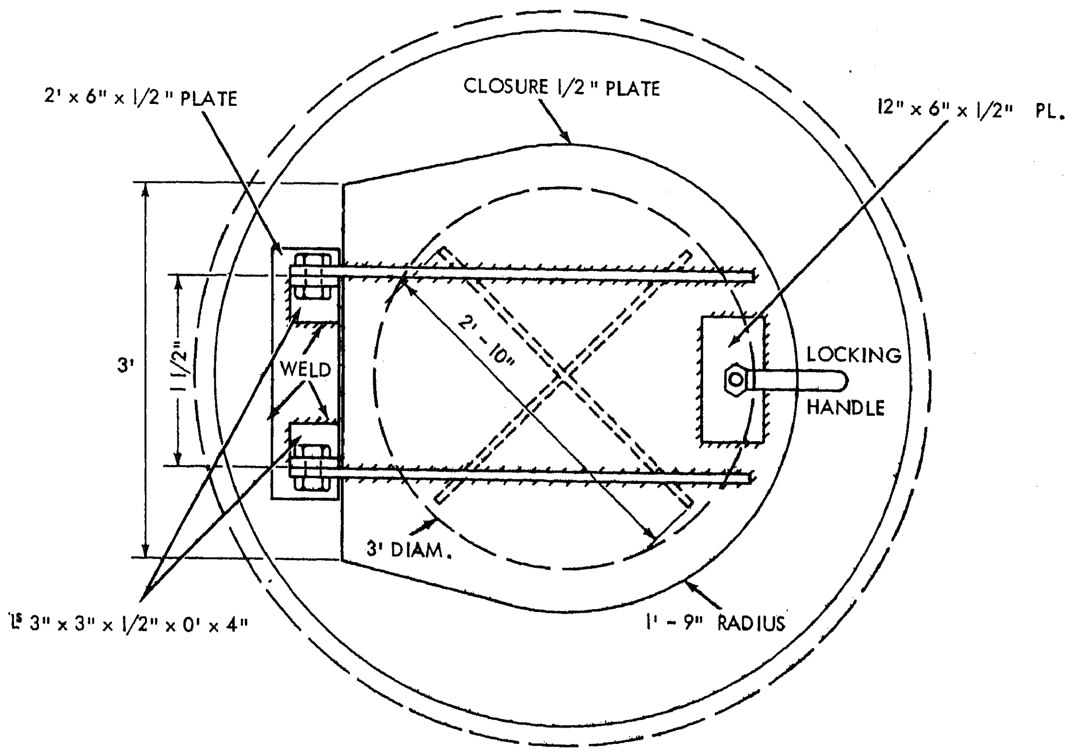


Figure 144. Designed personnel hatch plan.

should be hung for door-like operation with gravity employed to keep the hatch open except when the required locking devices are in place.

d. Designed Walkthrough Door. The blast closure shown in figures 145 and 147 designed fro mstandard structural steel shapes should be employed only when use of the smaller personnel hatch is not possible. The disadvantages of this type closure are the weight of the door, the vulnerability of vertical faces to reflected pressures greater than those for which designed (note the increase in the reflected to side-on overpressure ratio with increased pressure (fig. 12), and the poor radiation shielding given by such entrances. The walkthrough door is suitable as a second door for in-tunnel placement when used with a hatch with a vertical entrance. If available, a small blast-closure hatch from stock should be used as a means of reducing the door weight and construction effort required.

e. Massive Drawbridge Door. The massive steel door illustrated in figure 148 is for use when a drive-in or large entrance is required. The design is one that has been successfully tested at reflected nuclear blast overpressures of aproximately 180 psi (12.8 kg/sq cm), varied slightly for additional strength. The door provides negligible instantaneous radiation shielding, requires a large construction effort, and is awkward to open or close slowly enough to prevent damage. Doors which roll to the side are unsuitable due to the likelihood of jamming, though such designs have been tested in both vertical and horizontal orientations. The drawbridge door shown does provide a known ability to resist the blast pressure, and in addition provides very rapid opening post-shot (if required and if the damage to the door upon falling is acceptable).

130. Earth Cover

a. Purpose. The purpose of the earth cover over a structure is to provide protection from reflected overpressure and dynamic pressure. The earth cover also gives radiation protection.

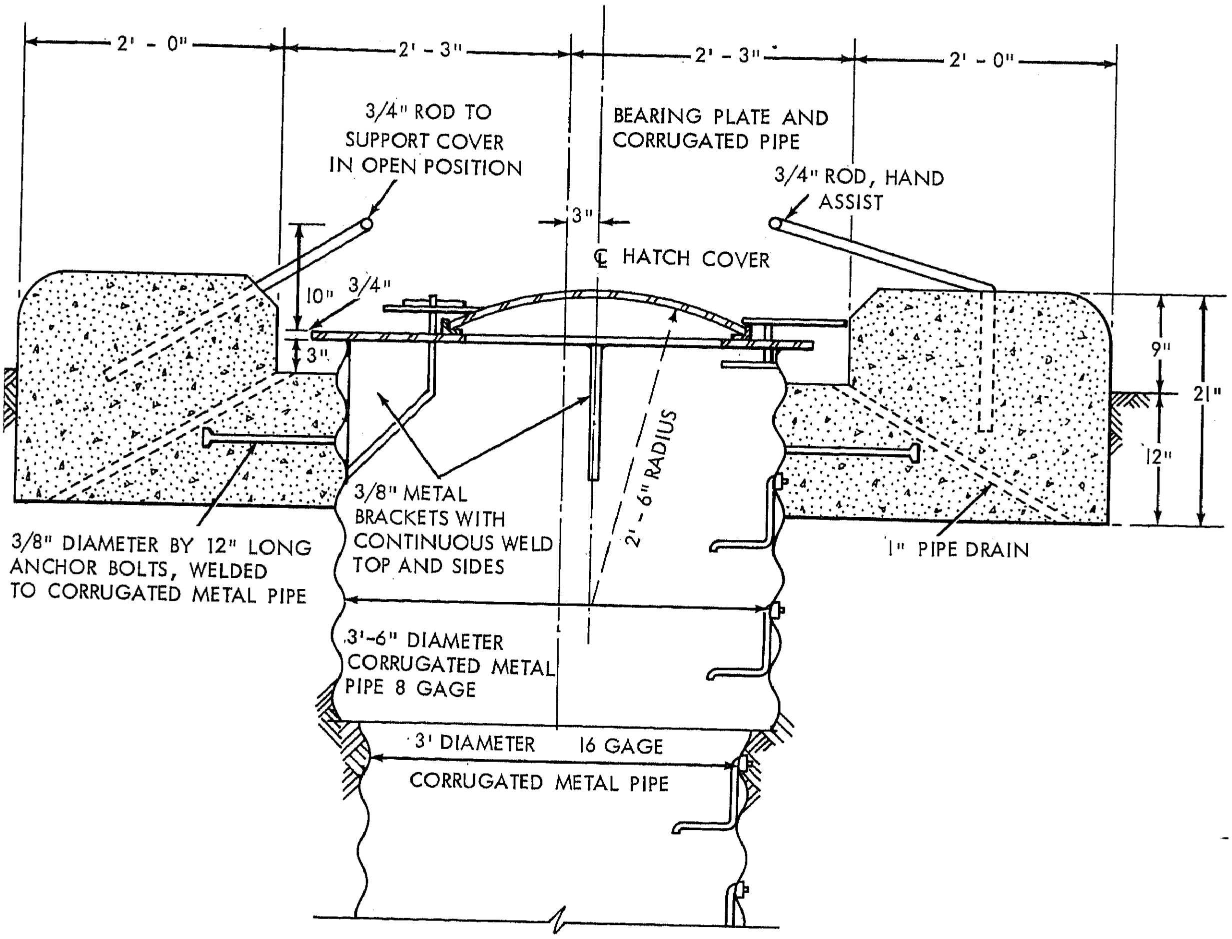


Figure 145. Standard employment of a stock steel hatch section.

The earth berm configurations shown in figure 126 have been designed to prevent reflected overpressure and dynamic pressure from harming the structure. These berms should force arch structures to respond in the compressive mode. Although there appears to be some attenuation of pressure transmitted to a buried structure, it is probably unsafe to assume any attenuation unless the structure is buried deeper than its span.

b. Berms. Most soils will stand on a slope of 1.5 horizontal to 1 vertical; therefore this is used as the design slope. However, slopes on the order of 3 to 1 or 4 to 1 should be used if the soil permits, since such slopes give greater streamlining of the cover. Streamlining serves to reduce reflected and drag pressures. The berm should be constructed of the best material available and compacted at optimum content. The backfill should be placed in equal lifts around the structure. In order to prevent differential loading of the structure while backfilling, one side should never rise higher than 1 foot above the other side. When compacting close to the structure, small hand compacting equipment should be used. To avoid damage to the structure, heavy compaction equipment should not pass closer than 6 feet from the structure or 6 feet from a vertical line through the springing line of an arch.

c. Material. The best materials are well-graded crushed rock, gravel, and sand. These are materials which have high shearing resistance. Properly placed, they are practically

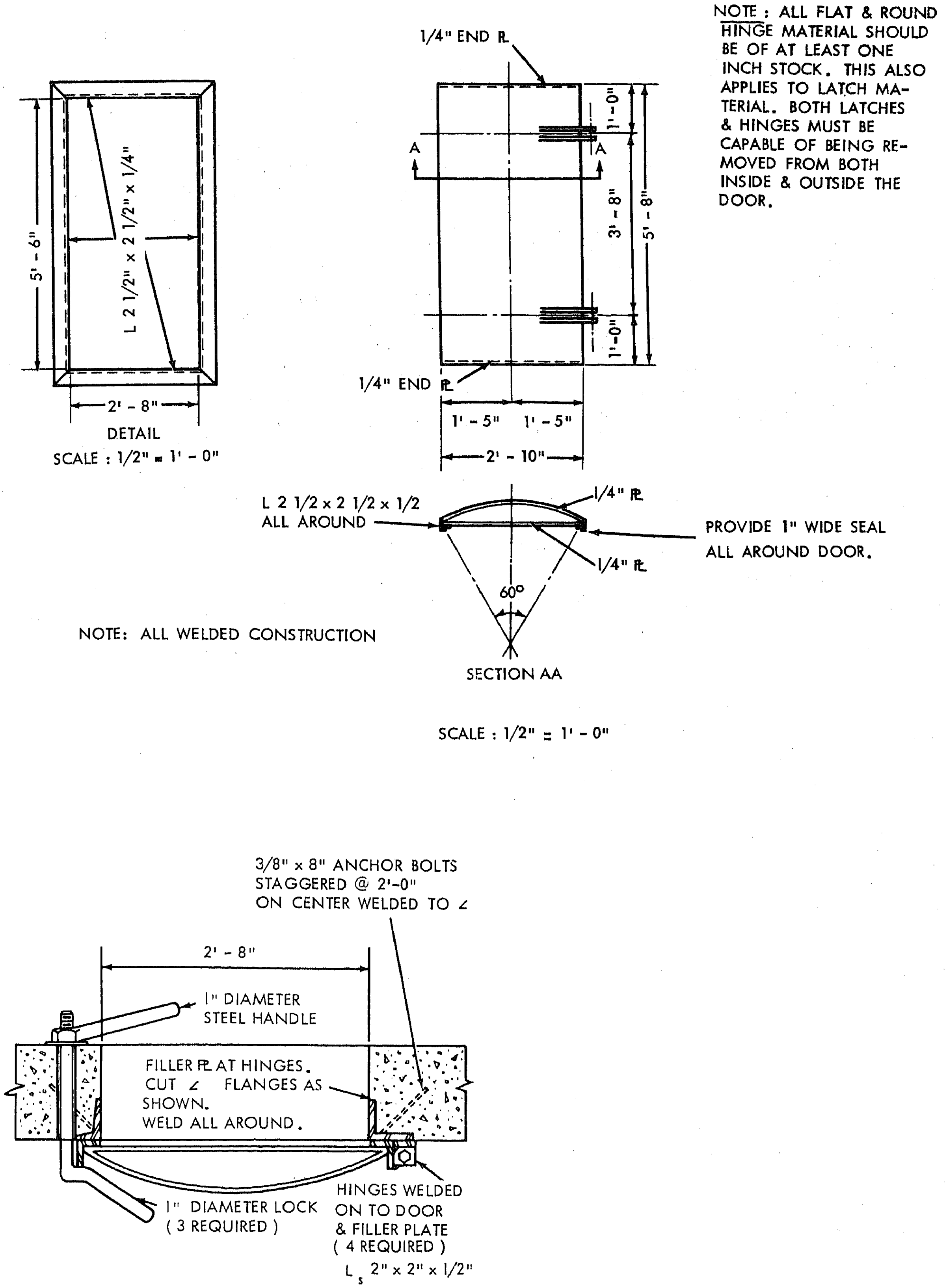


Figure 146. Stock steel door design.

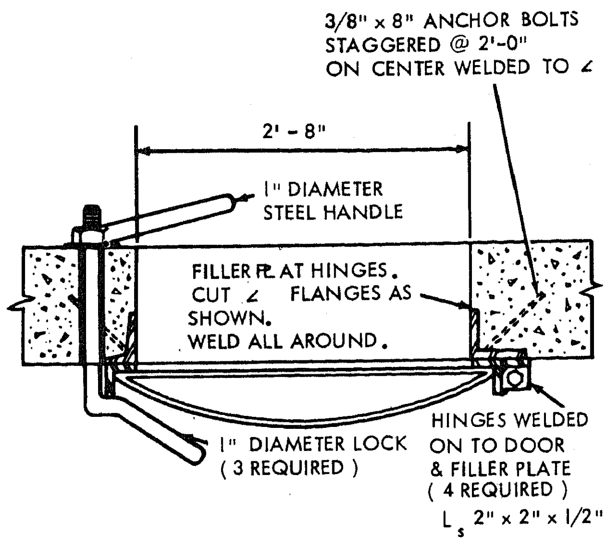


Figure 147. Stock steel door frame.

incompressible and they drain well without special drainage requirements. Dirty or silty sands and silts are second-choice materials because they resist compaction, drain relatively slowly, and are not as strong as the more granular materials. If used, they must be placed with great care or eventually they will exert excessive pressures against the walls of the structures. Clays are poor backfill materials. They cannot be drained satisfactorily, they shrink as they dry, and they swell as they become wet. Clays are also likely to be quite compressible and will lead to undesirable settlement. Their use should be avoided whenever possible. Organic materials such as peat will not be used.

d. Backfill Control. The importance of inforcing correct backfill procedures cannot be overemphasized. The backfill must be compacted in 6-inch layers and each layer properly compacted. The material must be clean and free of trash. To insure a correct job requires constant supervision. *For example,* if the material is brought in by a bulldozer, a truck, or a clamshell, it is usually heaped or dumped in a pile several feet thick. This will probably always be the case since heavy equipment is prohibited from working within 6 feet of these structures. Then the pile is spread over the area of the backfill into a 6-inch layer. The question is whether the pile will be reduced to a 6-inch layer at its deepest part. It is only natural to spread as little dirt as possible, and if this is done a loose accumulation of dirt, perhaps 1 or 2 feet thick, will remain at the location of the pile. This loose material can be compacted at the top but not at the bottom. Thus, a layer of weakness will exist in the backfill. The loose material taken from the excavation may be stockpiled nearby and pushed into the hole by a bulldozer when backfilling is started. There will probably be men with pneumatic tampers in the bottom of the hole to compact the fill in layers, but if the material is pushed in too fast the men will not be able to compact it because they must work on top of the material. If the soil is added faster than effective compaction can be carried out, the backfill cannot be considered properly compacted. It is possible that entire loads of material may be dumped so rapidly that they receive no compaction at all. Naturally, the upper part of the fill, which is visible to all, will be carefully compacted. However, if any loose material exists within the fill, it will be a zone of weakness.

e. Foundations. Soil usually has much greater shearing strength or bearing capacity under dynamic loading; therefore, the usual criteria stated in terms of allowable footing pressure are not applicable. The total area of the footings and floor slab under the protective structures considered in this manual will not exceed the area of the roof. These buried structures will, in general, behave in the same way as the surrounding soil under blast pressures. It is desirable to place the structure above the water table. If the structure is below the water table, the problems of hydrostatic uplift, waterproofing, and drainage must be considered. The structures in this manual are designed to be placed above the water table with two exceptions—the reinforced-concrete arch and reinforced-concrete rectangular structure. It is possible to construct these structures below the water table but this placement is highly undesirable.

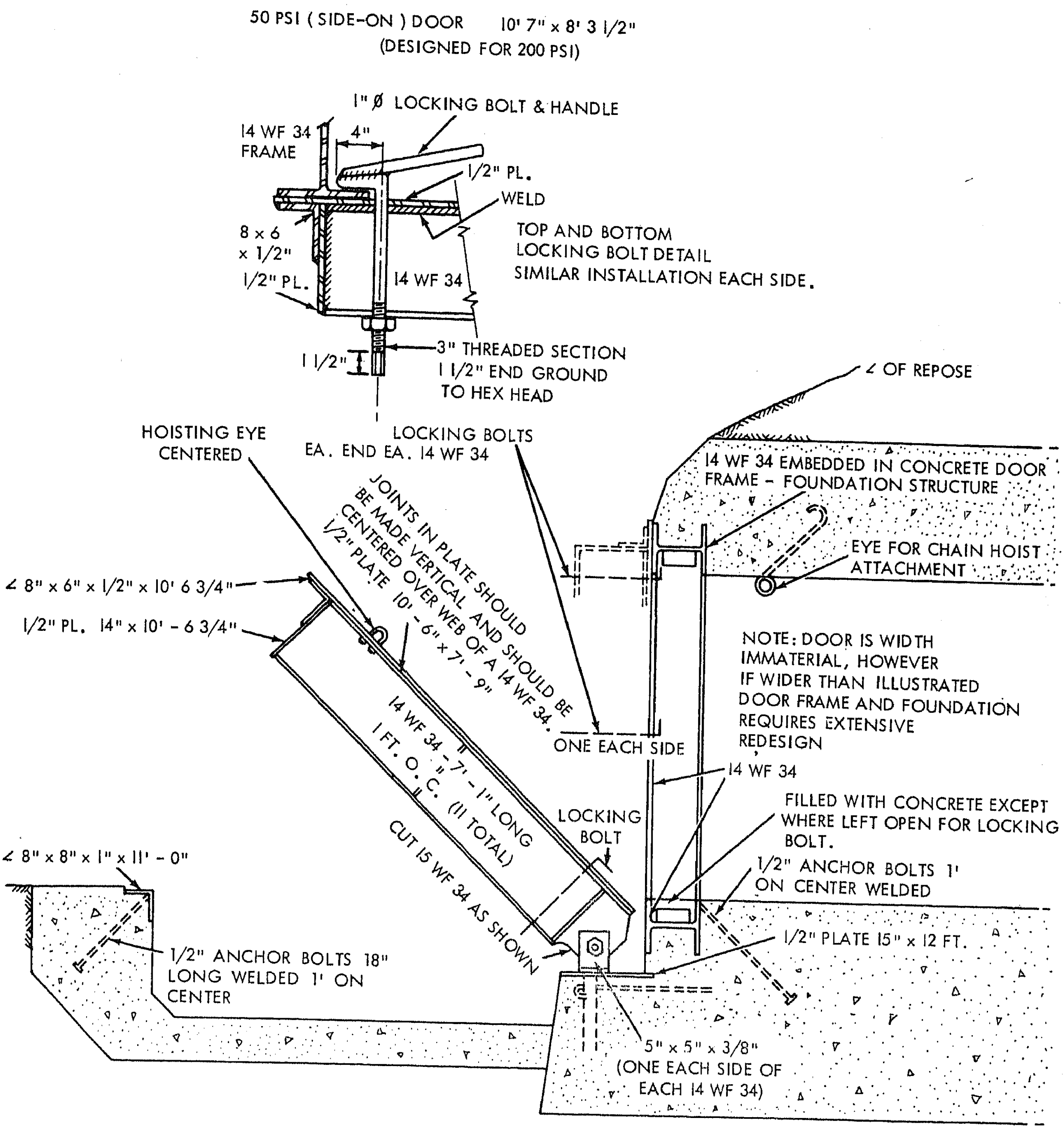


Figure 148. Massive drawbridge door.

Section III. REINFORCED CONCRETE BURIED STRUCTURES

131. Circular Reinforced Concrete

a. Reinforced-Concrete Pipe. Prefabricated, reinforced-concrete pipe is usually locally manufactured and stocked for sewer and culvert installations. The industry has not adopted long term standards for construction, reinforcement placement, or design. The shapes used would be from existing stocks or provided by specified order. The design as presented in this manual is empirical, using current design

standards, and with field tests to determine pipe suitability.

b. Behavior When Buried. The theoretical behavior of buried circular concrete sections under blast loading is as follows: Upon the arrival of the shock front there is a slight tendency for the top of the conduit to be asymmetrically loaded as the shock wave passes from one side of the structure to the other. When the section is completely surrounded by the loading force, the pressure load tends to prevent further asymmetrical deformation. The conduit responds to an essentially symmetrical radial load with only compression in the concrete.

c. Response to Phases of Loading. The response of the structure to the two phases of loading described is an initial deformation into an elliptical shape (horizontal), at which time the forces transmitted through the earth to the sides of the conduit and the bending-moment capability of the quarter points resist further deformation. If cracking does not occur at the points of critical bending moment, the entire conduit is displaced downward; however, the resistance of the soil prevents appreciable total vertical movement. In the second phase of the loading the conduit resists the radial load by pure arch action and the bending-moment capability of the section is employed to prevent further displacement due to deformation of cracked sections at the quarter points.

d. Response to Loading. Nuclear and nondestructive tests confirm by the nature of the structure response, deformation, and cracking that in both flexural and compressive modes occur and consequently require flexural steel reinforcing. The section shown is set forth as a basic structure for a 50-psi (3.5 kg/sq cm) overpressure region. This section withstood 136-psi (9.5 kg/sq cm) side-on pressure, during which ¼-inch cracks appeared at the quarter points. At 56-psi (4 kg/sq cm) overpressure, cracks were slight and no deformation occurred. Cracking reduces stiffness available for resistance to subsequent attacks. Thus, a lighter section was not considered justified by the tests of the illustrated culvert section (fig. 149).

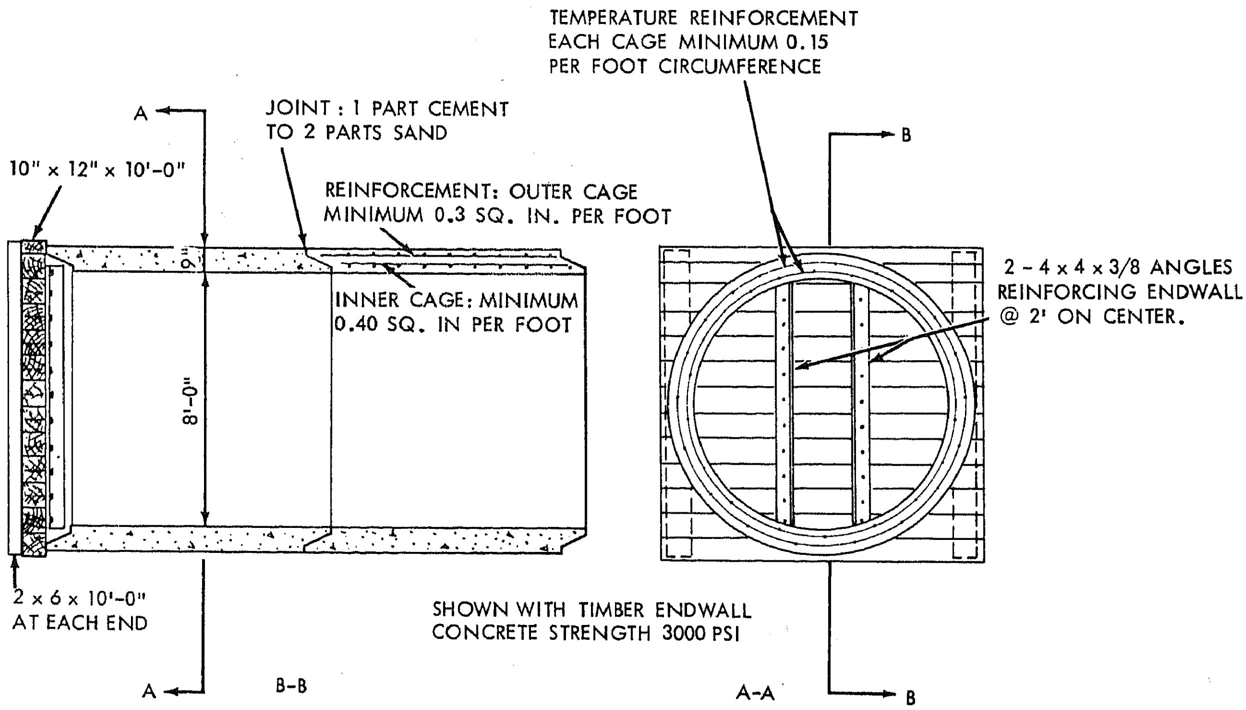
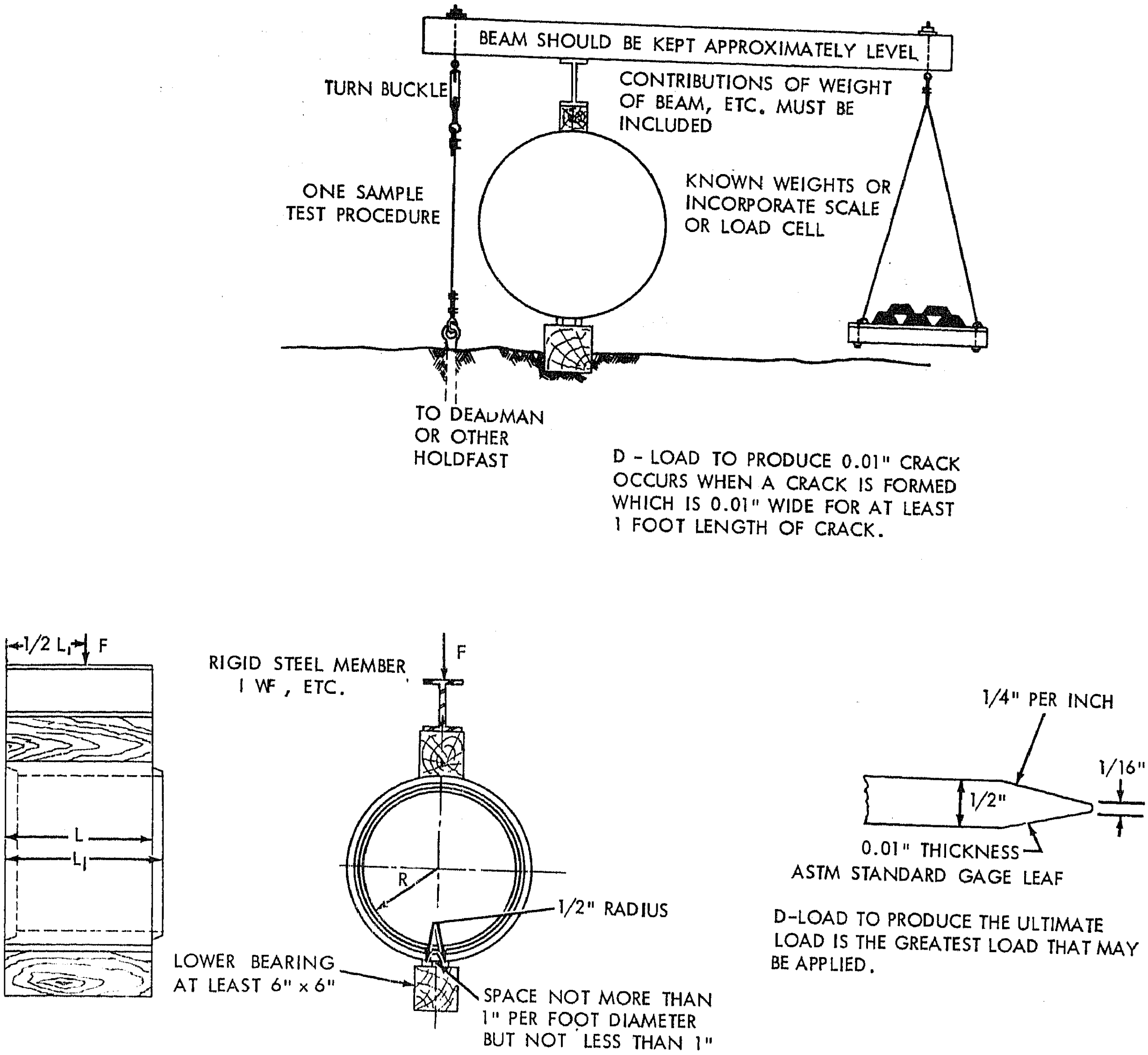


Figure 149. Circular concrete structure (horizontal placement), suitable for 50-psi, side-on overpressure.



$$\text{D - LOAD} = \frac{F}{2.R.L.} \left(\frac{\text{POUNDS}}{\text{FT. DIAM. FT. LENGTH}}\right)$$

REQUIREMENTS OF 50 PSI - SIDE - ON OVERPRESSURE, ENTRANCE OR HORIZONTAL STRUCTURE
D - LOAD (0.01" CRACK) NOT LESS THAN 750
D - LOAD (ULTIMATE) NOT LESS THAN 1100

Figure 150. Concrete pipe test procedure.

e. Specifications. The section shown in figure 149 has less strength than the American Society of Testing Materials (ASTM) design requirements for class I reinforced-concrete pipe. The other ASTM specifications for reinforced-concrete pipe, for classes II through V, provide still greater strengths. Reinforced-concrete pipe is graded by strength from a loading test, the results of which are expressed as the "D-load (test load expressed in pounds per linear foot per foot of diameter) to produce a 0.01-inch crack" and the "D-load to produce the ultimate load." The testing procedure for determining these D-loads is shown in figure 150.

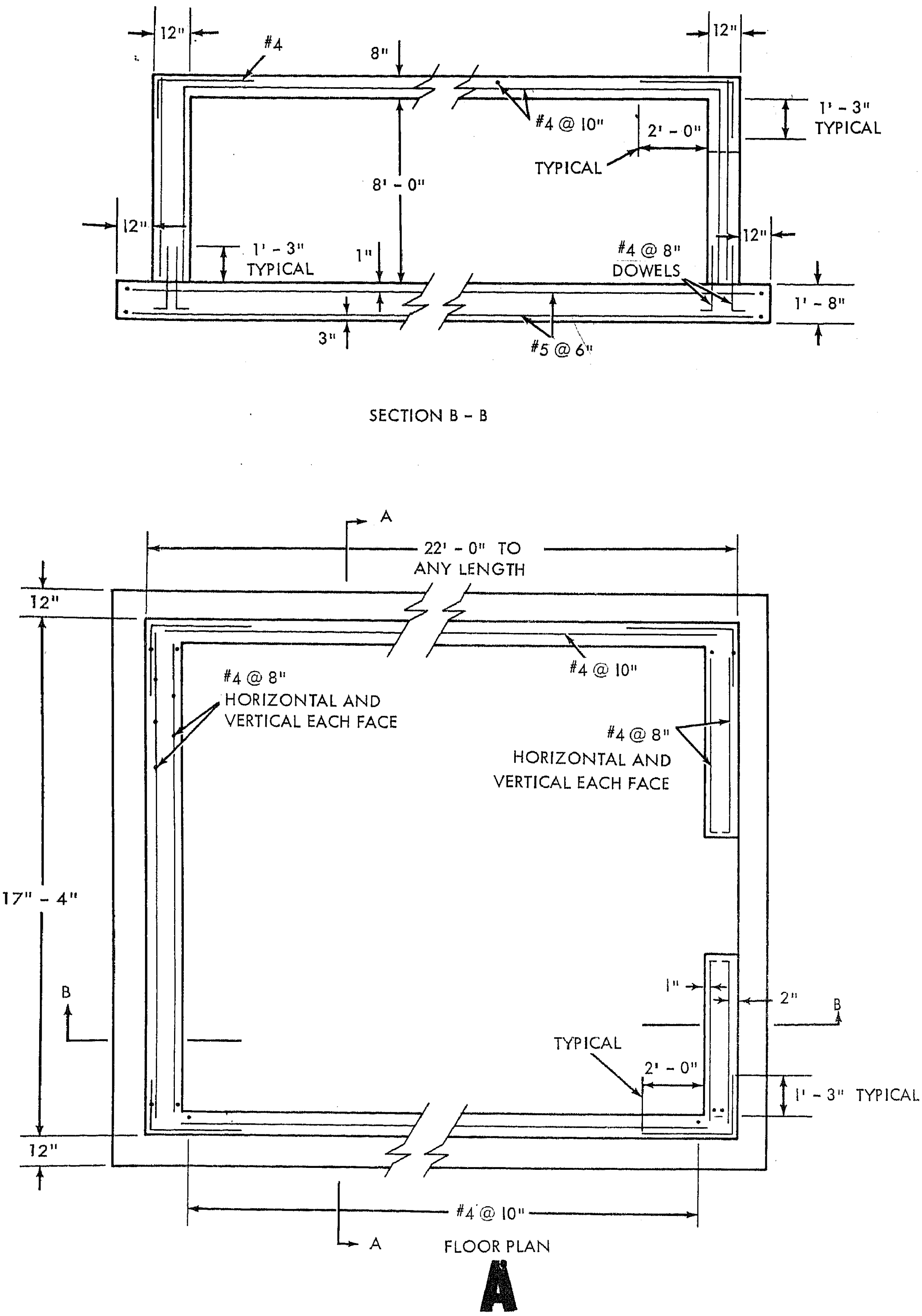


Figure 151. Reinforced concrete arch (part 1 of 2).

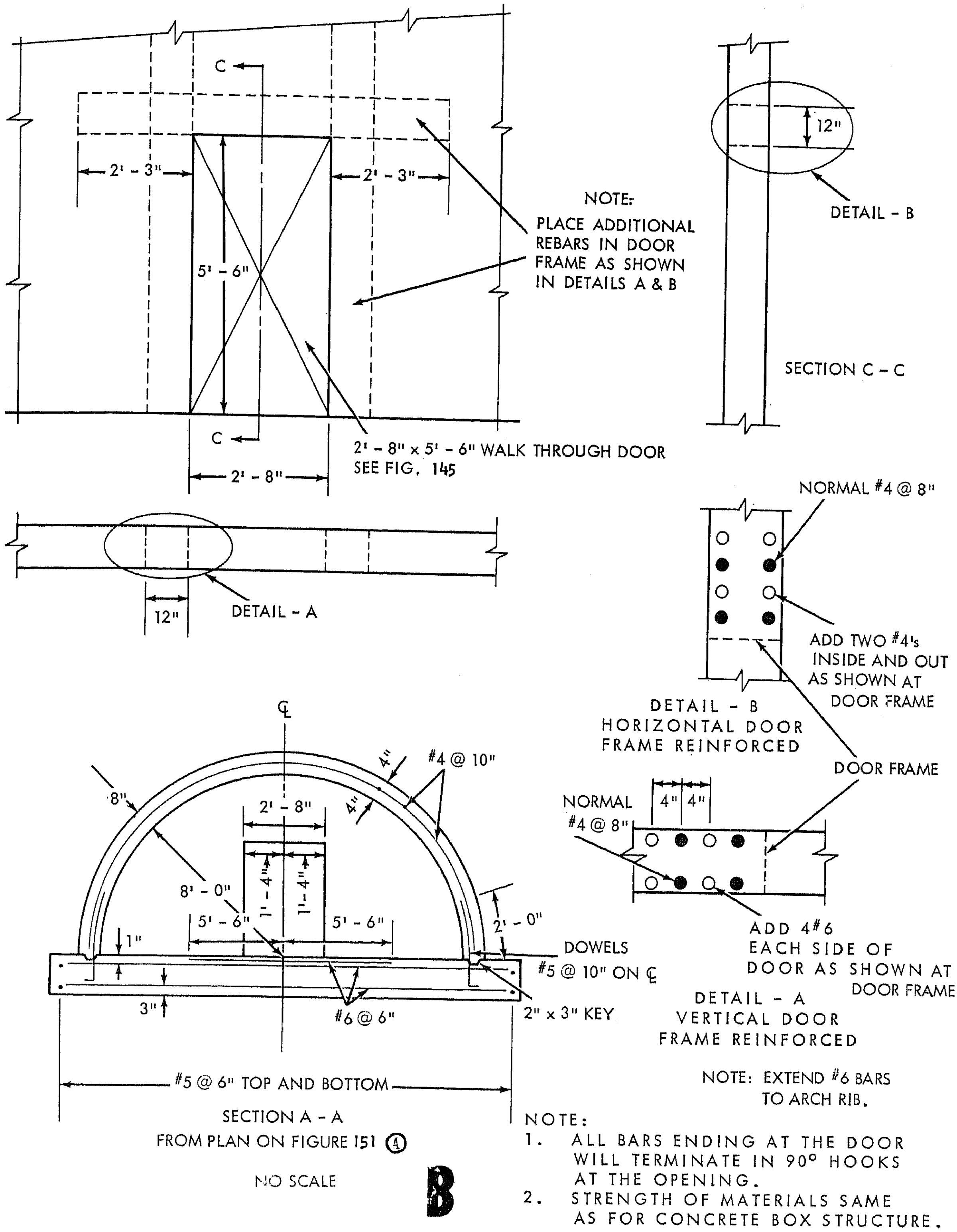


Figure 151. Reinforced concrete arch (part 2 of 2).

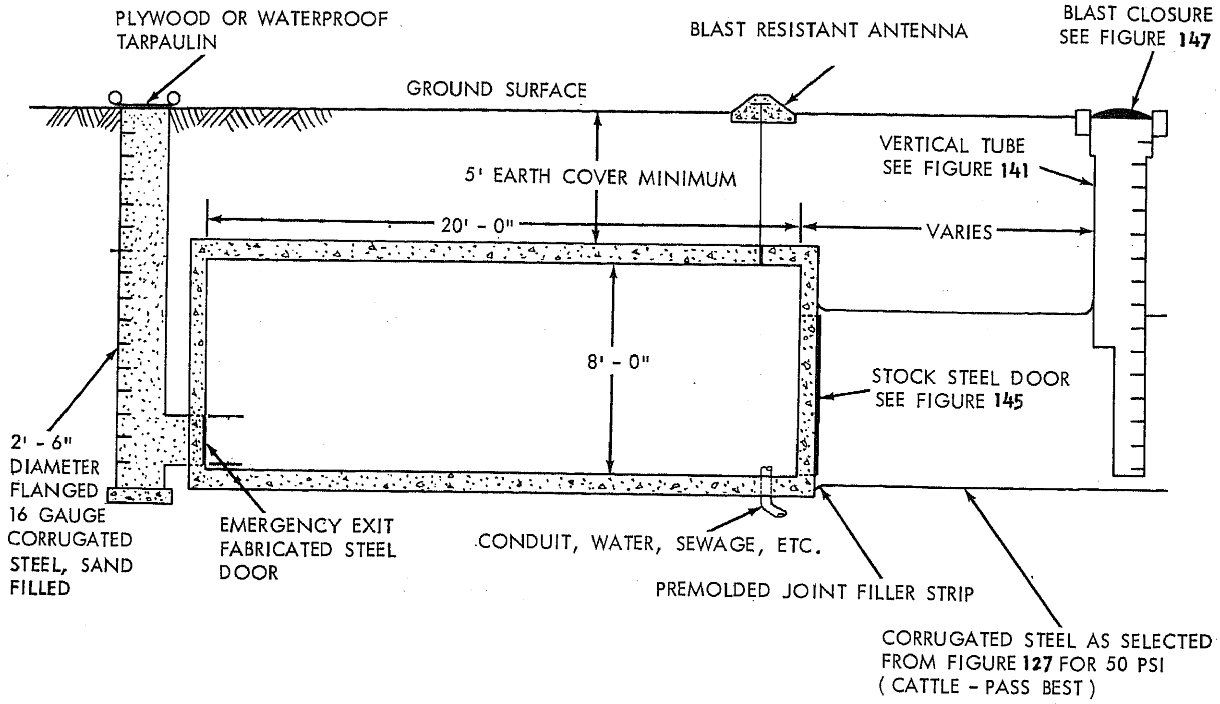


Figure 152. Suggested arrangements of components with rectangular, reinforced-concrete structure.

The identical test structures which adequately withstood loadings from one nuclear test, of up to 136-psi (9.5 kg/sq cm) side-on overpressure, had "D-load to produce a 0.01-inch crack" of 750 (pound per linear foot per foot of diameter) and "D-load to produce the ultimate load" of 1,100. The respective D-loads for class I pipe are 800 and 1,200; for class II, 1,000 and 1,500; for class III, 1,350 and 2,000; for class IV, 2,000 and 3,000; and for class V, 3,000 and 3,750.*

f. D-Loads. In those situations in which reinforced concrete pipe is on hand and the method of manufacture is not known, it is recommended that the D-loads be determined by test on a sample section. As the computation of the D-load provides for the effect of varying diameter sections, those pipe sections which meet 750 and 1,100 pounds per foot of pipe per foot of diameter of a 0.01-inch crack and ultimate, respectively, may be considered adequate for the 50-psi (3.5 kg/sq cm) side-on overpressure region in horizontal structures or in vertical entrances, for all section diameters.

132. Circular Reinforced-Concrete Arch

a. Introduction. Reinforced concrete has long been considered an excellent material to resist the dynamic loading resulting from nuclear explosions. In the design of the concrete arch structure shown in figure 151 (Parts 1 and 2), only the symmetrical response which corresponds primarily to compression in the arch was considered. The earth berms and depth of cover criteria have been designed to force the arch to respond in the symmetrical mode. This structure *will not* be constructed without cover. The structure may be constructed to any length desired but the 8-foot radius must remain constant.

b. Basis of Design. The design is based on an incident peak overpressure of 50 psi (3.5 kg/sq cm) at the ground surface with an effective

* To convert to metric measurement: pound per linear foot per foot of diameter equals 4.9 kg per linear meter per meter of diameter.

positive duration of 0.635 second. Where empirical results disagreed with theoretical requirements the proven empirical results were used. This 8-foot-radius (2.4-meter) concrete arch is one of the few structures in this manual which can be used where a structure must be built below the water table. It should be emphasized that construction below the water table is highly undesirable.

c. Waterproofing. Standard waterproofing techniques must be used to protect the structure. Some type of exterior drainage, such as french drains, may be necessary around such a structure.

d. Structural Weakness. Extreme care must be taken to avoid introducing local structural weakness such as holes in the roof and walls for conduits, equipment mountings, and similar purposes. If reinforcing steel is cut out by these openings, the cutout steel must be used to reinforce the opening in an appropriate manner.

e. Entrances. While only one entrance is shown in the plans, the same type entrance may be constructed in the opposite endwall. All exits will be made through the endwalls only. Only one exit per endwall is permissible. One exit should be the regular exit while the other will be the emergency type exit. The entrance will consist of a vertical shaft to horizontal passage constructed of materials capable of withstanding 50 psi (3.5 kg/sq cm). These materials may be selected from the appropriate table in this manual. The horizontal passage will terminate at the concrete endwall. The joint between endwall and passageway will be appropriately sealed to prevent earth from sifting into the passageway. The stock steel door (fig. 146), will be the only cutout in the endwall; therefore the passageway must be large enough to permit opening the door. This stock steel door will not be considered as the main blast protection door; therefore, if it cannot be fabricated, a dust-tight wooden door will be substituted. The height of the door cutout may be reduced as necessary without resulting in any change in the reinforcing steel. The same additional steel as shown in the entrance reinforcement details (fig. 151) (parts 1 and 2), is placed in the first 12 inches (0.3 m) above the top of the door frame. The width of the door cutout cannot be changed. Another hatch flush with the surface as shown in figure 145 will be used to prevent overpressure from entering the passageway.

f. Orientation in Relation to Blast. This structure should be oriented to present the arch to the probable direction of the blast (fig. 124).

133. Rectangular Reinforced-Concrete Structure

a. Description. This structure (fig. 153, parts 1–4), is a reinforced-concrete rectangular box with inside floor dimensions of 20′ 0″ (6 m) by 10′ 0″ (3 m) and a vertical clearance of 8′ 0″ (2.4 m). The structure is designed to resist 50-psi (3.5 kg/sq cm) overpressure with a positive phase duration of 0.635 second when covered as shown in figure 126. This structure will not be constructed without cover.

b. Positioning. This structure will be constructed below the water table, if necessary, but such employment is undesirable. If possible the roof, walls, and floor should be poured integrally far below the water table construction. Some type of exterior drainage, such as french drains, may be necessary around such a structure.

c. Entrances. While only one entrance is shown in the plans (fig. 153, part 1), the same type opening may be constructed in the opposite 8- x 10-foot wall to provide two entrances. All entrances will be made through the endwalls only. Only one entrance per endwall is permissible. One entrance should be the regular entrance while the other will be the emergency type exit. Wooden doors may be substituted for the steel doors since the blast resistance will be provided by the hatch cover over the vertical shaft. The height of this door may be shortened as necessary without resulting in any change in the reinforcing steel. The same additional steel or steel beam as shown in the entrance reinforcement details (fig. 153, 1–4), is placed in the first 12 inches above the top of the door frame. The width of the door cutout cannot be changed.

d. Passageway. The cattle-pass corrugated steel section is particularly well suited for use as a passageway leading from the steel door to

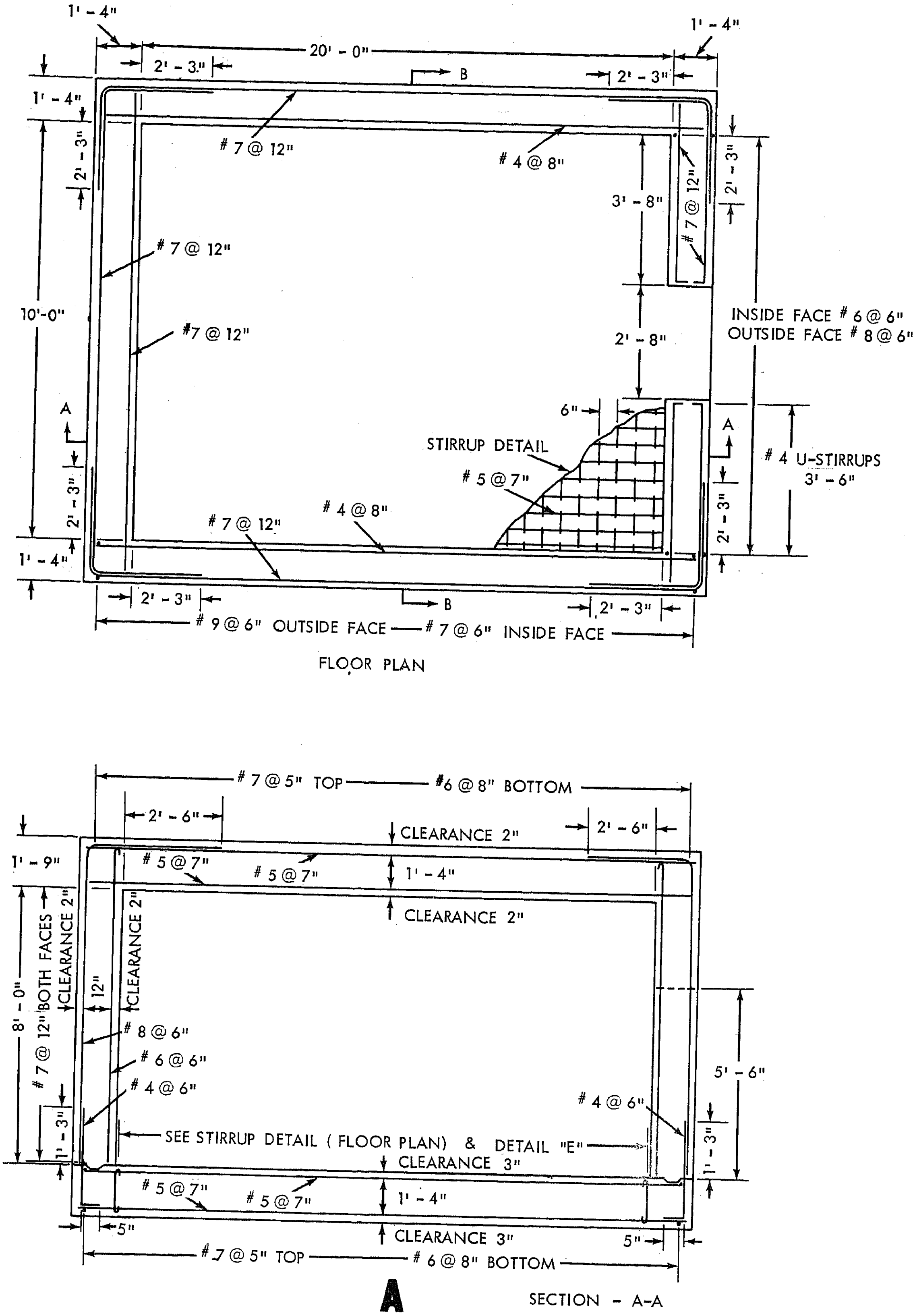
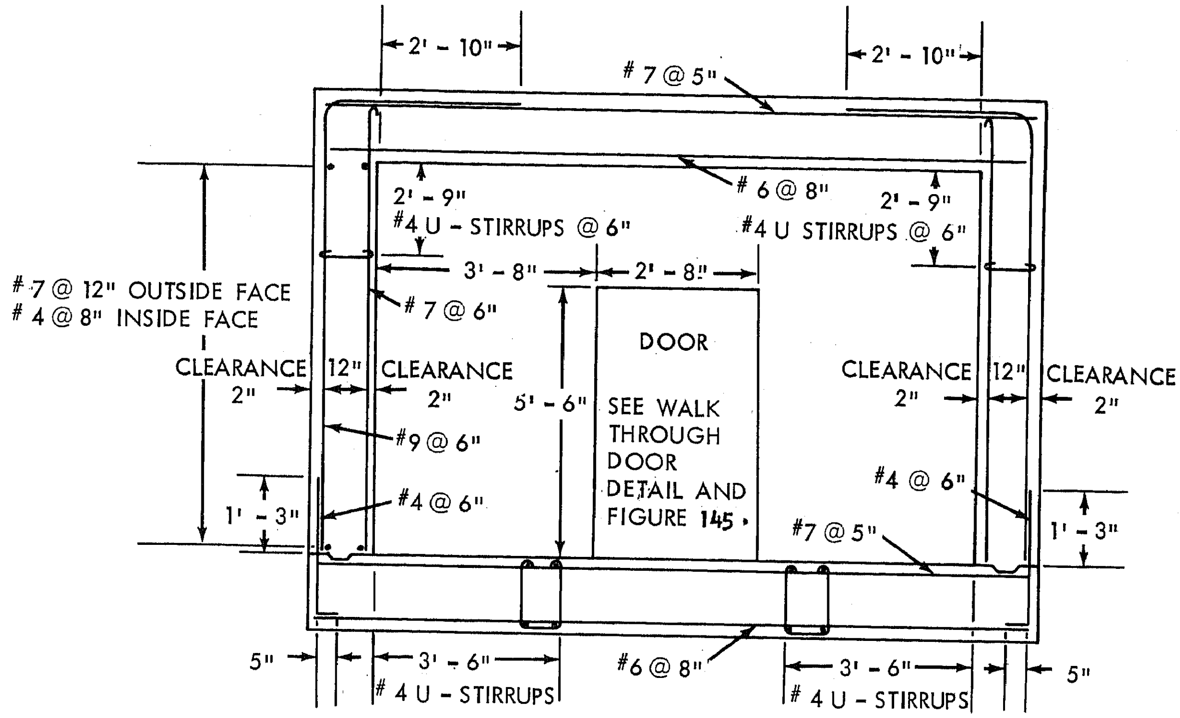
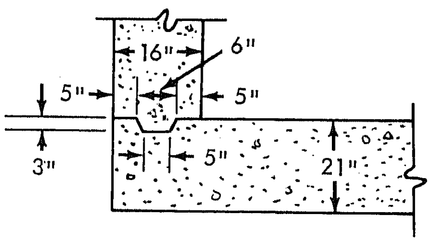


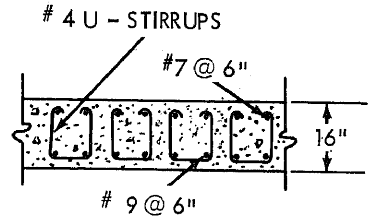
Figure 153. Rectangular, reinforced-concrete structure (part 1 of 4).



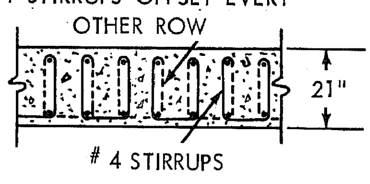
SECTION - B-B



DETAIL - "C"
WALL - FLOOR SLAB
CONSTRUCTION JOINT



DETAIL - "D"
WALL STIRRUP DETAIL



DETAIL - "E"
FLOOR STIRRUP DETAIL

NOTES :

STRENGTH OF MATERIALS :	DYNAMIC STRESS
SOIL BEARING CAPACITY	6000 PSF
CONCRETE $f'd_c = 1.25\ f'c$	3750 PSI
REINFORCED STEEL (INT. GRADE ASTM-A305)	52000 PSI
STRUCTURE STEEL (ASTM-A7)	52000 PSI

CAPABLE OF RESISTING Ps = 50 PSI

B

Figure 153. Rectangular, reinforced-concrete structure (part 2 of 4).

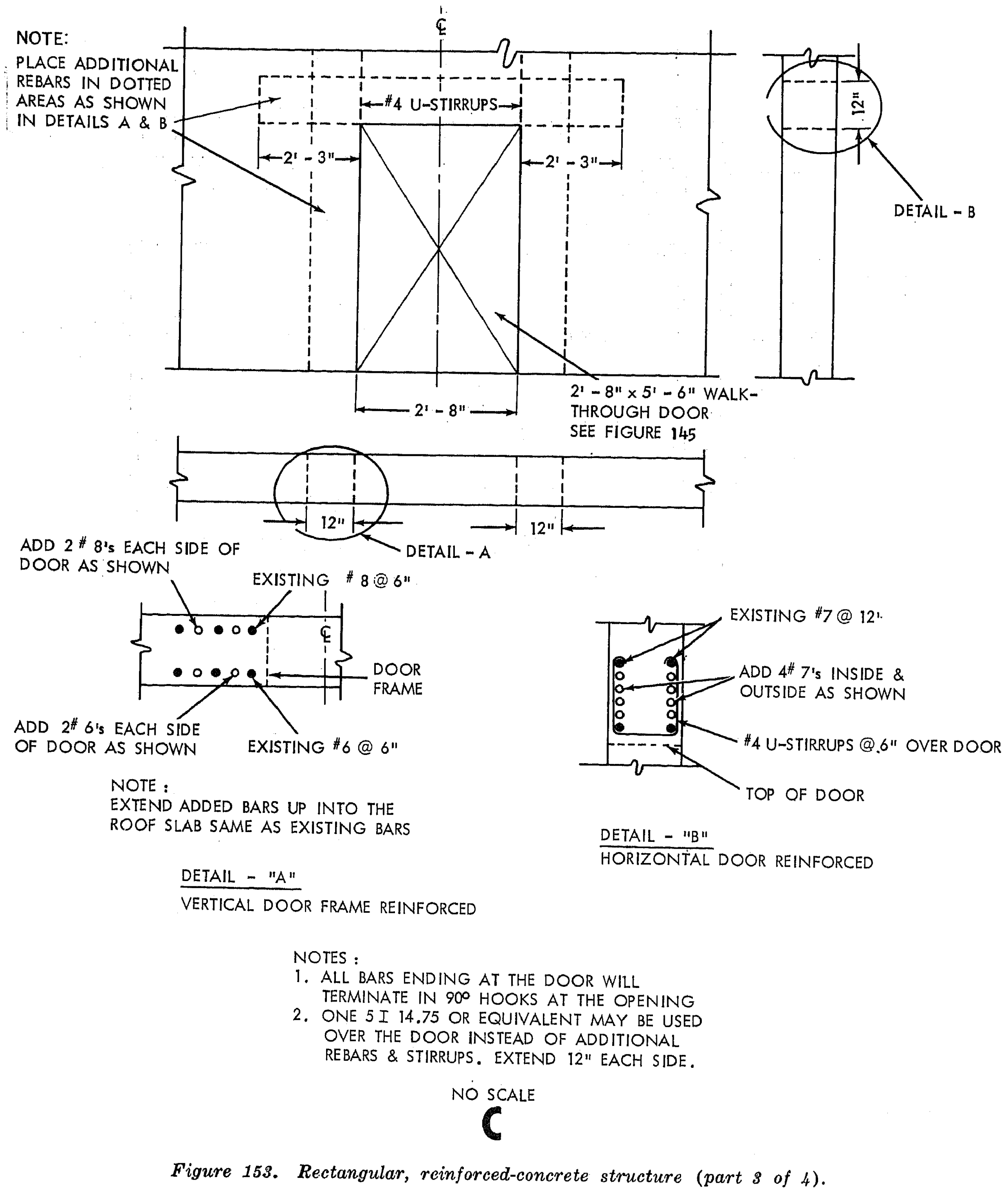


Figure 153. Rectangular, reinforced-concrete structure (part 3 of 4).

the vertical shaft or to another concrete structure. The 5′ 8″ span by 6′ 6″ rise is the minimum section which can be used with the stock steel door.

e. Structural Weakness. Extreme care must be taken to avoid introducing local structural weaknesses such as holes in roof and walls for conduits equipment mountings, and similar

REINFORCING	NUMBER PIECES	STOCK	BENDING
FLOOR SLAB	44	# 5 x 22' - 4"	STRAIGHT
	35	# 6 x 12' - 4"	STRAIGHT
	55	# 7 x 12' - 4"	STRAIGHT
	139	# 4 x 3' - 1"	4" – 2' - 9"
	240	# 4 x 4' - 3"	6" 6" 1' - 4" 1' - 4" 7"
WALLS (WITH DOOR IN EACH 8' x 10' WALL)	92	# 9 x 13' - 7"	4' - 0" – 9' - 7"
	92	# 7 x 10' - 5"	10" – 9' - 7"
	124	# 4 x 3' - 1"	4" – 2' - 9"
	18	# 7 x 29' - 2"	3' - 5" – 22' - 4" – 3' - 5"
	26	#4 x 22' - 4"	STRAIGHT
	36	# 8 x 13' - 3"	3' - 8" – 9' - 7"
	36	# 6 x 10' - 3"	8" – 9' - 7"
	24	# 7 x 5' - 2"	6" – 4' - 8"
	24	# 7 x 8' - 7"	3' - 11" – 4' - 8"
	12	# 7 x 19' - 2"	3' - 5" – 12' - 4" – 3' - 5"
	16	# 7 x 7' - 2"	STRAIGHT
	120	# 4 x 3' - 6"	6" 6" 1' - 0" 1' - 0" 6"
ROOF	44	# 5 x 22' - 4"	
	35	# 6 x 12' - 4"	
	55	# 7 x 12' - 4"	D

Figure 153. Rectangular, reinforced-concrete structure (part 4 of 4).

purposes. All electrical service and other pipes should exit through the floor of the structure if at all possible. No large holes should be cut in the roof. The air intake and exhaust pipes may exist through the walls of the structure at any point at least 2 feet (0.6 m) above the floor slab, 2 feet from either wall, and 4 feet (1.2 m) from the roof slab. If reinforcing steel is cut out by these openings, the cutout steel must be used to reinforce the opening in an appropriate manner. A typical shelter with this structure is shown in figure 152.

CHAPTER 7

EXAMPLE DESIGN

Section I. INTRODUCTION

134. Objective

This chapter is devoted to the sample design of a corrugated steel shelter incorporating all of the design criteria which relate to the hazards produced by nuclear weapons. An example situation is cited which is intended to depict representative shelter requirements which would be encountered or should be considered in an actual situation.

135. Selection of Shelter Components

a. Guides. The engineer is to be guided in the design and selection of the shelter components by the data given within this manual. Although most of the design can be accomplished directly from context, the engineer's judgment will be required to combine the shelter components into a usable unit satisfying the particular situation.

b. Components. The completed shelter design should include the main structural configuration, entrances and emergency exits, radiation protection, and facilities to meet the functional and environmental needs or the shelter operations.

Section II. SAMPLE SITUATON

136. Mission

The corps commander has assigned to the corps engineer the mission of hardening a rear area relay station to 50 psi (3.5 kg/sq cm) overpressure. This will increase the concealment potential of the site and reduce its vulnerability to small-yield nuclear weapons. The corps engineer, through command channels, reassigned the mission to the combat engineer group headquarters supporting corps. The group commander assigned to his staff the mission of making a reconnaissance, checking available materials and making a rough design to guide the engineer battalion which will be assigned the work.

137. Situation At The Site

a. Personnel and Equipment.

(1) Reconnaissance showed that the signal facility has a steady complement of 16 men. Security is provided by an infantry platoon of 44 men plus 2 cooks. The site should operate continuously and must be put back into operation again by personnel at the site if the facilities are damaged. To do this, personnel and the major signal components at the site must be protected.

(2) The signal relay equipment requires 20 KW of electric power. The signal equipment will not operate efficiently at dry bulb (DB) temperature exceeding 90°F. (32.2°C.). Normal conditions for continuous operation within a shelter should be maintained at 75°F. (24°C.) DB and 50 percent relative humidity. Central power is now being provided by two 30-KW generators in an aboveground building.

b. Space Requirements. The present minimum space requirements as indicated by a site

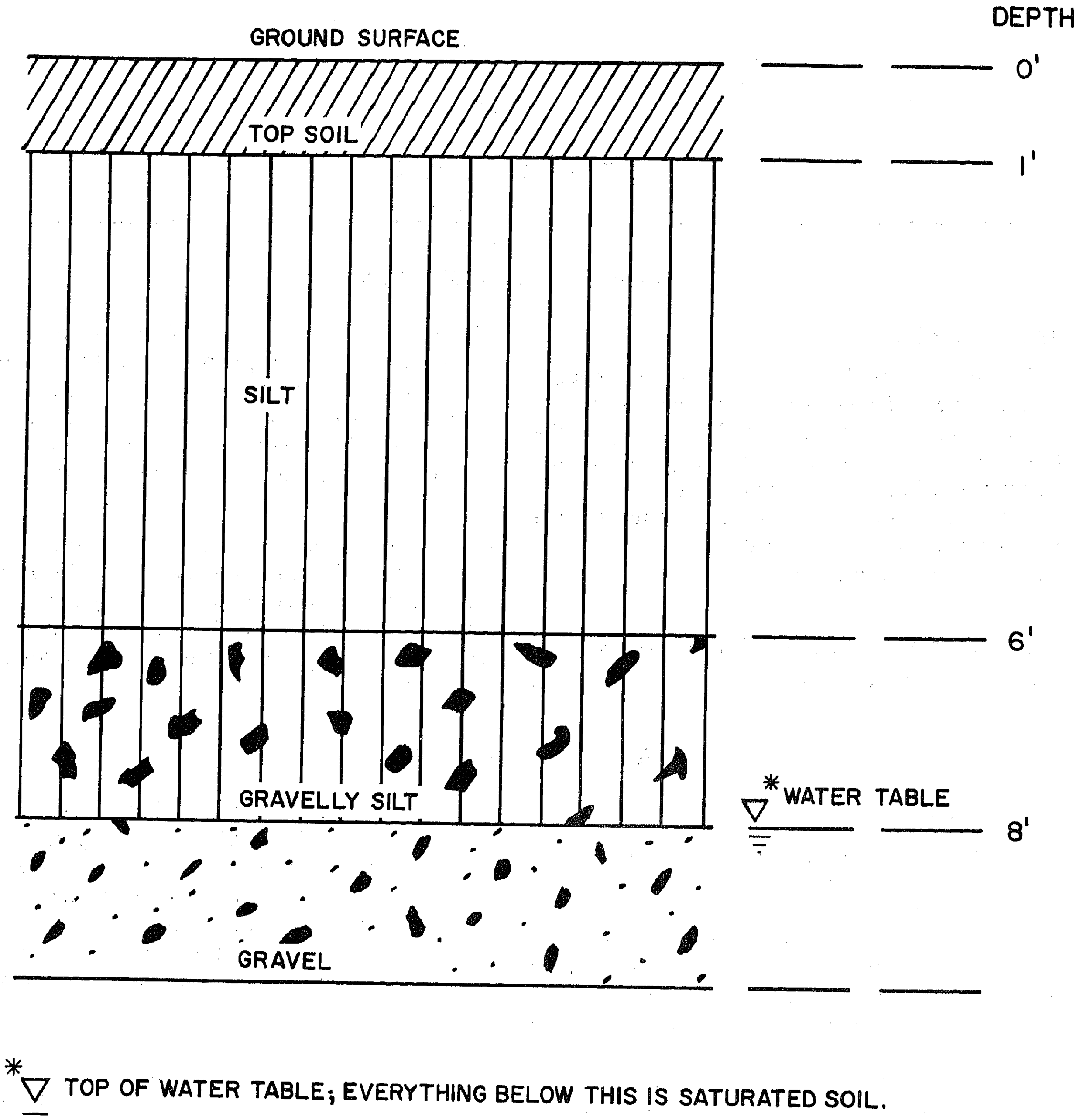


Figure 154. Soil profile.

inspection and discussions with the operating personnel revealed the following:

Equipment* (largest piece
3′ x 5′ x 6½′) = 400 sq ft

Working Area = 200 sq ft

Administration and living accommodations = 400 sq ft

1,000 sq ft (93 sq m)

Therefore, a minimum of 1,000 square feet total floor area is the estimated requirement

---

* This equipment must be moved out of the shelter if shelter evacuation is ordered.

for continuous operations. The site survey indicated that twenty 10-watt light bulbs will be required on the main shelter. A well, with enough water for the personnel on the site, exists nearby. For July and August, the average daily high temperature is 90°F. DB, and the relative humidity is 50 percent.

c. Soil. An earth auger boring revealed the soil profile shown in figure 154.

138. Available Materials and Equipment

a. Materials. The materials available in the supply depot are listed in table XXX.

Table XXX. Materials in Supply Depot

Material	Size	Gage
Corrugated metal sections*	15-ft radius	5
	12½-ft	5, 7, or 8
	10-ft	10 or 12
	9-ft	8, 12, or 14
	8-ft	10, 14, or 16
	6-ft	8, 12, or 14
	4-ft	12
	3½-ft	12, 14, or 16
	3-ft	10, 14, or 16
Corrugated steel sheating	------------	3
Steel plate	6 ft x 10 ft	(½-inch)
Lumber	(all sizes)	
Cement	(bag)	
Sand and gravel	(on site)	

* With bolts

b. Equipment. Tables XXXI and XXXII list the special equipment available in the supply depot. In addition to the special equipment listed in those tables, there are also available two 15–KW, AC generators and two 30–KW, AC generators at depot.

Table XXXI. Air Filter Units Available in Supply Depot

Designation	HP	Electric power (in KW)	Approximately capacity	
			cfm	cu m/min
M6A1	1	1.25	300	8.5
M9A1	1	1.25	600	16.8
M10A1	2	2.5	1200	33.6
M11	5	6	2500	70.0
M12	7.5	10	5000	140.0

Table XXXII. Air Conditioners Available in Supply Depot

Quantity available	Approximate capacity		Maximum power requirements (in KW)	
	BTU/hr	cal/hr		
4	9,000	2,268,000	1.8	Single-phase 60-cycle, 115 volt
3	18,000	4,536,000	3.0	
2	32,500	8,190,000	6.0	Three-phase, 60-cycle, 210-volt
2	38,000	9,576,000	11.0	
1	60,000	15,120,000	11.4	

139. Design Requirements

Based on the reconnaissance and surveys, the S3 should provide a design of the facilities, including sketches.

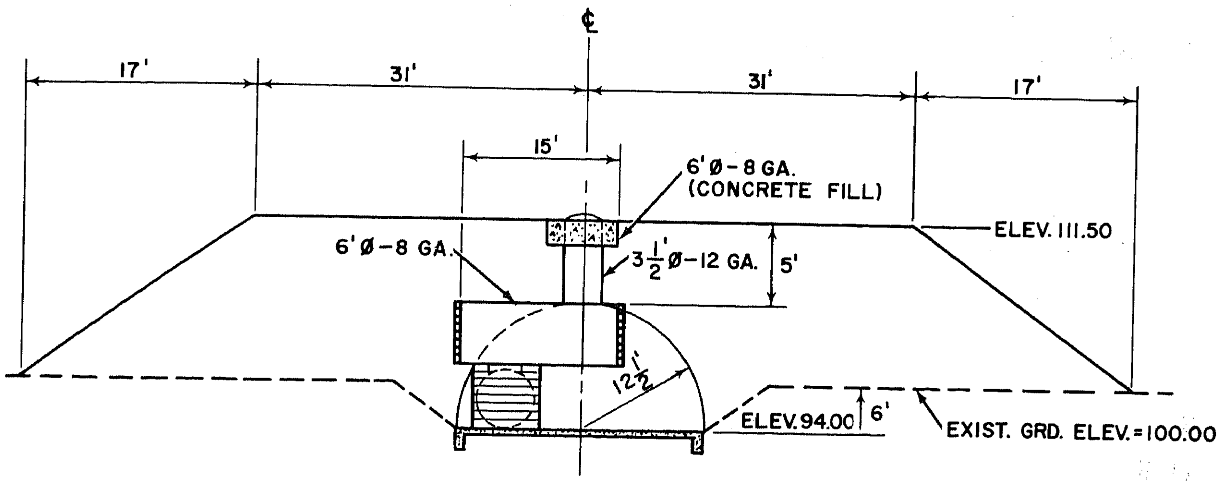


Figure 155. End view—earth berm details.

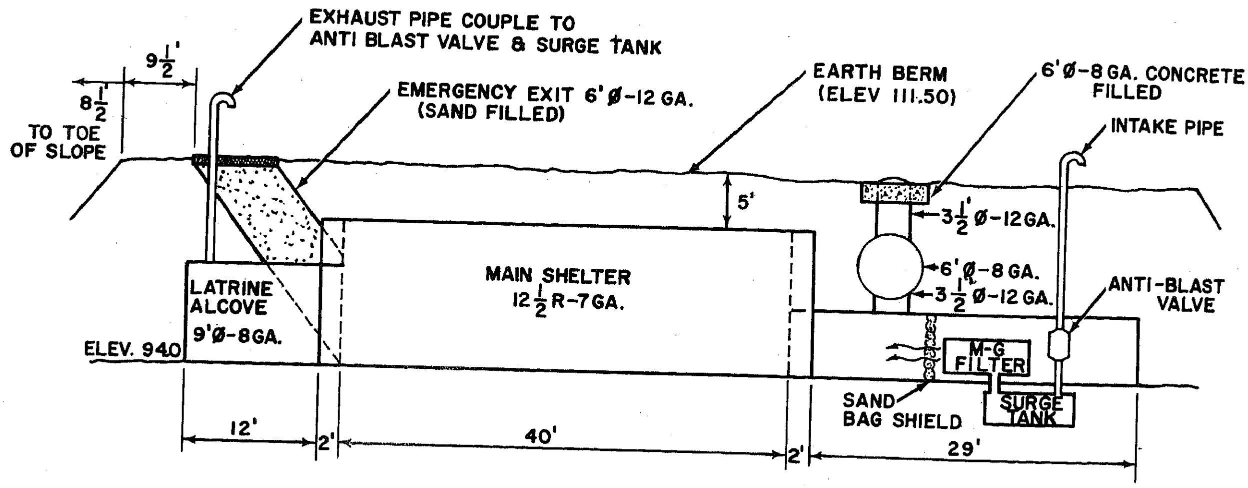


Figure 156. Side view—earth berm details.

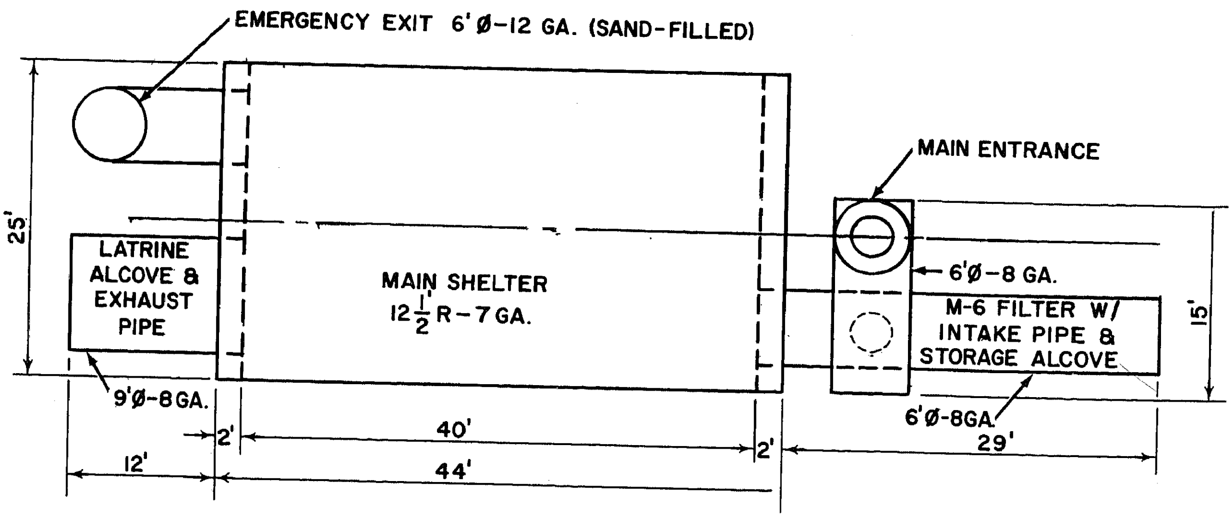


Figure 157. Plan view—earth berm details.

a. Sketches of Elevation View. These sketches should show the following (figs. 155 and 156).

(1) Gage sizes used.

(2) Diameter or radius of corrugated arches or cylinders.

(3) Minimum earth cover requirements.

(4) Footing depth to top of footing.

(5) Type floors.

b. Sketch of Plan View. In this sketch the S3 should show (fig. 157).

(1) Layout of main structure with dimensions.

(2) Location of alcoves with dimensions.

(3) Location of entrances and emergency exits.

c. Illustrations. There should be a list of the

figure numbers from this manual which indicate the details to be used for the following:

(1) End wall.

(2) Footing.

(3) Hatch.

(4) Entrance.

(5) Air intakes and exhausts.

d. Air Filters and Conditioners. This is a description of the size and quantity of any air filters or air conditioners that may be required for the shelter.

e. Attenuation Factor. This part will give the attenuation factor for initial radiation provided by the proposed shelter design.

140. Design Factors

The following additional information was estimated by the S3 based on information given with the equipment specifications:

a. Assume all of the electrical power supplied to the signal equipment is converted to heat.

b. Assume all electric input energy to electric motors is converted to heat.

c. The heat from the electric motor within the air filter units is considered to enter the main shelter along with the air passing through the filter.

d. So much heat is produced by the engine-generator set that it is impractical to place this set in the main shelter. To isolate the additional heat load, it is therefore necessary to construct a separate pit for the engine-generator equipment.

Table XXXIII. Selection of Ultilities and Closures Based on Structure Utilization.

Intended structure employment	Recommended entrance [1]	Recommended electric power and lighting	Air treatment	Water supply	Sanitary utilities	Emergency[2] equipment
1 Storage	Vertical shaft (if possible). Horizontal and a small diameter vertical pipe with closure.	Battery lighting (and, if available, central power source).	None	Conventional water supply, if any, minimum storage.	Conventional units and outfall, or none.	Gastight seal for massive entrance.
2 Emergency, personnel, short duration.	Vertical pipe	Battery-powered lighting.	None, volume selected from table.	5-gallon cans storage.	None, or bucket-type, drainage to separate pit.	Radiation detection equipment.
3 Emergency, personnel, long duration.	Vertical pipe	Battery lights and an engine-driven generator.	Electric motor or engine-driven filter and exhaust.	5-gallon cans storage.	Bucket-type, latrine, drainage to separate pit.	Radiation detection, food supplies.
4 Personnel sleeping quarters and shelter.	Vertical pipe and emergency filled pipe.	Battery lights (if available a central power source) and an engine-driven generator.	Electric motor filter and exhaust (heater).	Conventional water supply and 5-gallon cans storage.	Conventional units and outfall, bucket-type with separate pit for emergency.	Radiation detection, food communications equipment.
5 Emergency-personnel working and living station, long duration.	Vertical pipe and emergency filled pipe.	Engine-driven generator; if available, central power source; and emergency battery power for lights and signal equipment.	Electric motor filter and exhaust (heater).	(Emergency water system) 5-gallon cans storage.	(Use of emergency water system) drainage to separate pit, bucket-type latrine.	Radiation detection, food, decon equipment, communications equipment.
6 Continuous occupancy working station.	Vertical pipe with two blast closures and emergency filled pipe.	Engine-driven generator, central power source, and emergency battery power for lights and signal equipment.	Electric motor ventilation/ filter exhaust, antibackdraft valves (heater, air conditioning).	Conventional water supply (emergency water system) 5-gallon cans storage.	Conventional units and outfall, bucket-type with drainage to separate pit.	Radiation detection, food, decon equipment, radiation monitor, clothing, gas masks.

7	Radiation decontamination station in conjunction with 3, 4, 5, or 6 above.	Vertical pipe with gastight partitions and emergency filled pipe.	Engine-driven generator, and emergency battery lighting.	Electric motor filter, exhaust, antibackdraft valves in partitions.	(Emergency water system) overhead or pumped shower feed, 5-gallon cans storage.	Drainage to large separate pit, bucket-type latrine showers.	Radiation detection, food, decon equipment, radiation monitor, clothing, gas masks.

[1] An airlock consisting of two personnel blast closures, each designed for full blast overpressure, is recommended for every personnel shelter.

[2] Emergency equipment of all underground structures—wrecking and entrenching equipment.

Section III. PLANNING

141. Introduction

The first step is to devise a plan for the selection or design of the shelter components which are needed or are considered in satisfying the overall requirements of the completed installation. This plan could be in the form of a simple outline such as the one written below (table XXXIII).

142. Space Requirements

a. Minimum area and volume for personnel living accommodations.

b. Minimum space for operational equipment.

c. Minimum space for storage of supplies and emergency equipment.

d. Engine-driven generator pit.
- (1) Pit location.
- (2) Pit design details.
- (3) Buried fuel storage tanks.
- (4) Related cables and fuel piping details.

143. Utilities Requirements

a. Air Treatment Equipment.
- (1) Electric-motor-driven ventilator with air filter.
- (2) Air-conditioning equipment required.
- (3) Intake and exhaust details.
- (4) Antibackdrift valves and antiblast valves for intake and exhaust.

b. Electric Power.
- (1) Basic operational equipment (signal equipment) and lighting.
- (2) Power required by the air treatment equipment.
- (3) Power required by pumps, for example, water supply pumps.
- (4) Emergency generator for signal equipment.
- (5) Emergency battery power for lighting.

c. Water Supply.
- (1) Distribution system from nearby well (pumps, piping, and fixtures).
- (2) Emergency water supply in storage.

d. Sanitation.
- (1) Conventional flush-type latrines.
- (2) Showering facilities.
- (3) Drainage pit or septic tank.
- (4) Related plumbing.
- (5) Emergency bucket type latrines.

144. Structural Requirements

a. Main Shelter.
- (1) Size the main shelter according to the area and volume requirements.
- (2) Type of construction determines the selection of materials.
- (3) Select the flooring, footing, and endwall details.
- (4) Select the buried depth and earth cover details.

b. Entrances for Personnel and Equipment.
- (1) Vertical pipe with two blast closures.
- (2) Airlock for personnel.
- (3) Emergency exit for personnel and equipment (sand-filled pipe).
- (4) Select door or hatch details.

c. Alcoves.
- (1) Latrine and shower alcove details.
- (2) Storage alcove details (optional).
- (3) Sleeping or bunking details.

Section IV. SOLUTION

Note. The following solution is intended not only to be a reasonable design for the particular situation just cited; it is also to serve as a guide for the systematic solution to any field protective shelter requirement. It should also be noted that all of the items listed in section III on planning are not included in this section. Because this outline is intended to be a guide for systematic shelter design, items are included for consideration which may or may not require design calculations for detailing selections. Some of these items are, more specifically, construction problems rather than design problems.

145. Example of Space Requirements

a. Assumptions. Assume that at least 3 cfm (0.08 cu m/min) per person mechanical ventilation will be available.

b. Space for Personnel. Based upon the above assumptions, paragraph 94 indicates that a minimum of 8 sq ft (0.74 sq m) per person and 60 cu ft (1.7 cu m) per person is required.

(These criteria include working, eating, and sleeping areas.)

(1) Minimum net area required—62 persons x 8 sq ft (0.74 sq m) per person = 496 sq ft (46 sq m).

(2) Minimum net volume required—62 persons x 60 cu ft (1.7 cu m) per person = 3,720 cu ft (105.3 cu m).

(3) Minimum space for operational equipment (from reconnaissance)—400 sq ft (37 sq m) for equipment

c. Storage.

(1) *Food—emergency supply* (See table XXVIII.)

C-rations 1.1 cu ft/6 rations

5-in-1 rations 0.8 cu ft/5 rations

Assault rations 1.3 cu ft/24 rations

Select 5-in-1 rations since these offer a better diet—

$$62 \text{ persons} \times 14 \text{ days}^* \times \frac{0.8 \text{ cu ft}}{5 \text{ rations}} \times$$

1 rations per day per person = 139 cu ft (4 cu m)

(2) *Water—emergency supply*

62 persons × ½ gal per day per person × 14 days = 434 gal

Use 500-gal tank

500 gal × cu ft/7.5 gal = 67 cu ft, allow 75 cu ft (2 cu m)

(3) *Fuel—emergency supply*

Note. This estimate is based on one 30-KW generator. If more power is required, revise this estimate accordingly.

Diesel engine requires 4.8 gal/hr

$$4.8 \text{ gal/hr} \times 14 \text{ days} \times \frac{24 \text{ hr}}{\text{day}} = 1{,}610 \text{ gal}$$

Using 5-gal storage cans requires—

$$1{,}610 \text{gal} \times \frac{1 \text{ can}}{5 \text{ gal}} = 322 — 5 \text{ gal cans}$$

$$1{,}610 \text{ gal x} \frac{\text{cu ft}}{7.48 \text{ gal}} = 215 \text{ cu ft (6 cu m)}$$

(4) *Oil* (See note under (3) above)

0.3 lb/hr × 14 days × 24/hr/day = 101 lb

Specific gravity of 30-weight oil equals 0.827

Volume storage required:

$$0.8927 \times \frac{101 \text{ lb}}{62.4 \text{ lb/cu ft}} = 1.45 \text{ cu ft (0.04 cu m)}$$

(5) *Emergency equipment.* Allow 10 cu ft (0.3 cu m) for radiation measuring devices and wrecking entrenching tools.

(6) *Summary of storage space required:*

Food (5-in-1 rations)	139 cu ft (4 cu in)
Water (500-gal tank)	75 cu ft (2 cu in)
Fuel* (minimum)	215 cu ft
Oil	2 cu ft
Emergency equipment	10 cu ft
Total storage	441 cu ft (12.5 cu in)

The additional storage space should be provided by a separate alcove off the main shelter.

d. Summary of Space Requirements.

Min. net area (personnel) =	496 sq ft (46 sq m)
Min. net area (equipment) =	400 sq ft (37 sq m)
Minimum total area	896 sq ft

Since the 1,000 sq ft (93 sq m) determined by the reconnaissance estimate provides more area than the minimum requirements, the main shelter should be proportioned to contain 1,000 sq ft. For ease and speed in construction, a simple structure under one roof should be designed as the main shelter. Additional space is then provided by special alcoves off the main shelter. In proportioning the main shelter, the minimum volume of 3,720 cu ft (105.3 cu m) must be considered.

146. Example of Structural Requirements

a. Main Shelter. It has been determined that 1,000 sq ft (93 sq m) of floor area is to be used and a minimum volume of 3,720 cu ft (105.3 cu m) is required. The type of construction which adapts to these requirements with a minimum time and effort for construction is the corrugated metal arch building. This arched structure is an example of design by "proved components" which is an engineering technique employing structural components that

* Maximum anticipated stay time in area of heavy fallout.

* Emergency fuel storage is provided by a buried tank near generator pit.

have been tested under actual loading conditions. All of the protective shelter components listed with this solution have been tested and found acceptable to withstand overpressures greater than the 50 psi (3.5 kg/sq cm) design loading. To design the facility it is only necessary to select the predetailed and proven components to satisfy the dimensional requirements.

b. Arch Design Selection. To satisfy the floor area of 1,000 sq ft, reasonable dimensions for the floor area are—40′ x 25′ or 50′ x 20′.* (These values are consistent with the radii available for the corrugated metal arch sections). Using figure 127 with a design overpressure of 50 psi, a check is made to determine the required gage size for a 10-ft (3-m) radius and a 12½-ft (3.8-m) radius. It is determined from this figure that, with the materials available, a 12½-ft. radius and 7-gage (minimum) corrugated metal arch is required.

Basic arch—12½-ft (3.8-m) radius
7-gage steel

Minimum length—40 ft (12m), plus 2 ft (0.6m) each end for overhang is required by endwall design = 44 ft (13.2m)

Volume check: $V = \frac{\pi r^2}{2} \times \text{length}$

$V = \frac{(12.5)^2}{2} \times 40 = 9{,}814$ cu ft $>$ 3,720 cu ft, min. or 728 cu m $>$ 105.3 cu m min.

c. Flooring Selection. Since the water table is high and the basic soil material is silt, a sand or earth floor would be wet and soft due to capillary action. Therefore, a concrete floor or sectional wood floor is recommended. For a concrete floor, use details given in figure 132. A sectional wood floor uses a wood sheathing wearing surface held by a 2- by 4-inch frame. The upper limit on dimensions of the sections should be held to 8 feet (2.4m) to provide a section which may be readily handled, moved, and replaced on the bearing soil. The flooring thickness and the size and spacing of the supporting cross members are solely determined by the use of the structure. The flexibility gained by the use of sections not rigidly joined and providing room for inward displacement of the basic structure's sides furnishes the resistance to damaging effects of the nuclear blast overpressures. Variations on this type flooring would be the employment of pallets or flooring sections placed only on those portions of the underlying earth floor where specifically needed.

d. Footing Selection. Basically, three footings are detailed for selection in figures 129 through 131. For this shelter problem, the concrete footing is recommended due to availability of materials and more permanent type construction.

e. Endwall Selection. The endwall details are given in figures 134 and 135. An adjustment of the details and dimensions is required to accommodate the 12½-ft (3.8-m) radius of the main arch. The main arch overhangs the endwall by 2 feet (0.6m) on each end. Note that the endwall is *not* connected to the main arch. It is reasonable to assume that the materials required by these details are available.

f. Earth Cover. A corrugated metal structure should not be built below the water table. Therefore, it will be necessary to place a berm over the structure. The required dimensions are given in figure 126. The results of a reasonable earth cover selection are given with the sketches in this solution.

g. Entrance and Emergency Exit Details.

(1) One entrance must be able to handle the signal equipment and miscellaneous equipment. The size of this entrance will be dictated by the size of the largest piece of equipment, which is 3 ft x 5 ft x 6½ ft in this case. To minimize construction effort, the emergency exit will be built large enough to initially receive this equipment. Once the operational equipment is inside the shelter, the emergency exit will be filled with sand and closed. Under emergency conditions, the sand is allowed to fall into the shelter, and the equipment removed.

(2) Emergency exit—minimum diameter $= \sqrt{3^2 + 5^2} = 5.84$ ft (1.8m) Therefore, use 6-ft (1.8m) dia. corrugated metal pipe. Any convenient gage is adequate, since the pipe will be sand-filled. Use the details in figure 143.

* In meters: 12 x 7.6 or 15.2 x 6

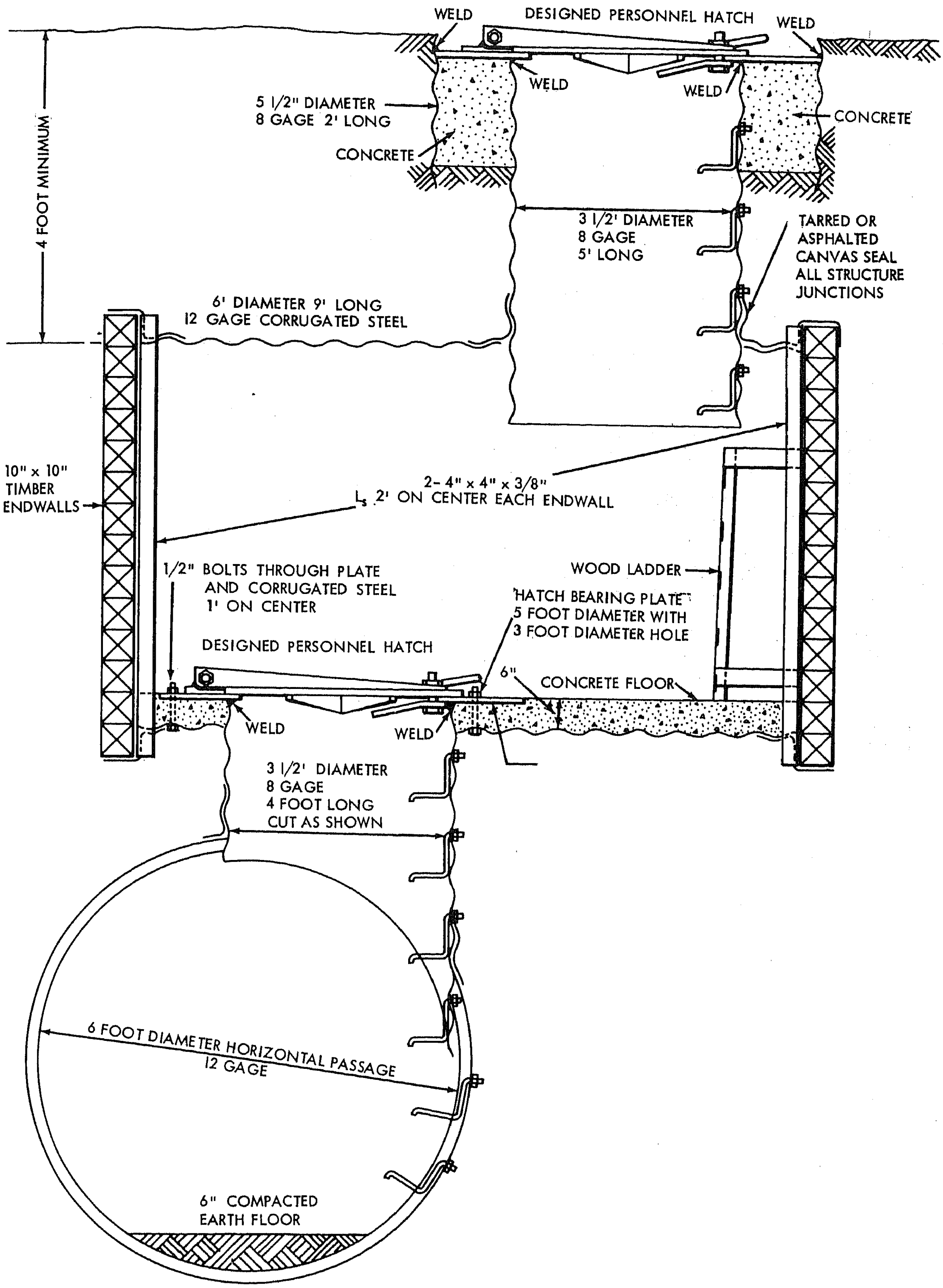


Figure 158. Entrance, continuous occupancy working station.

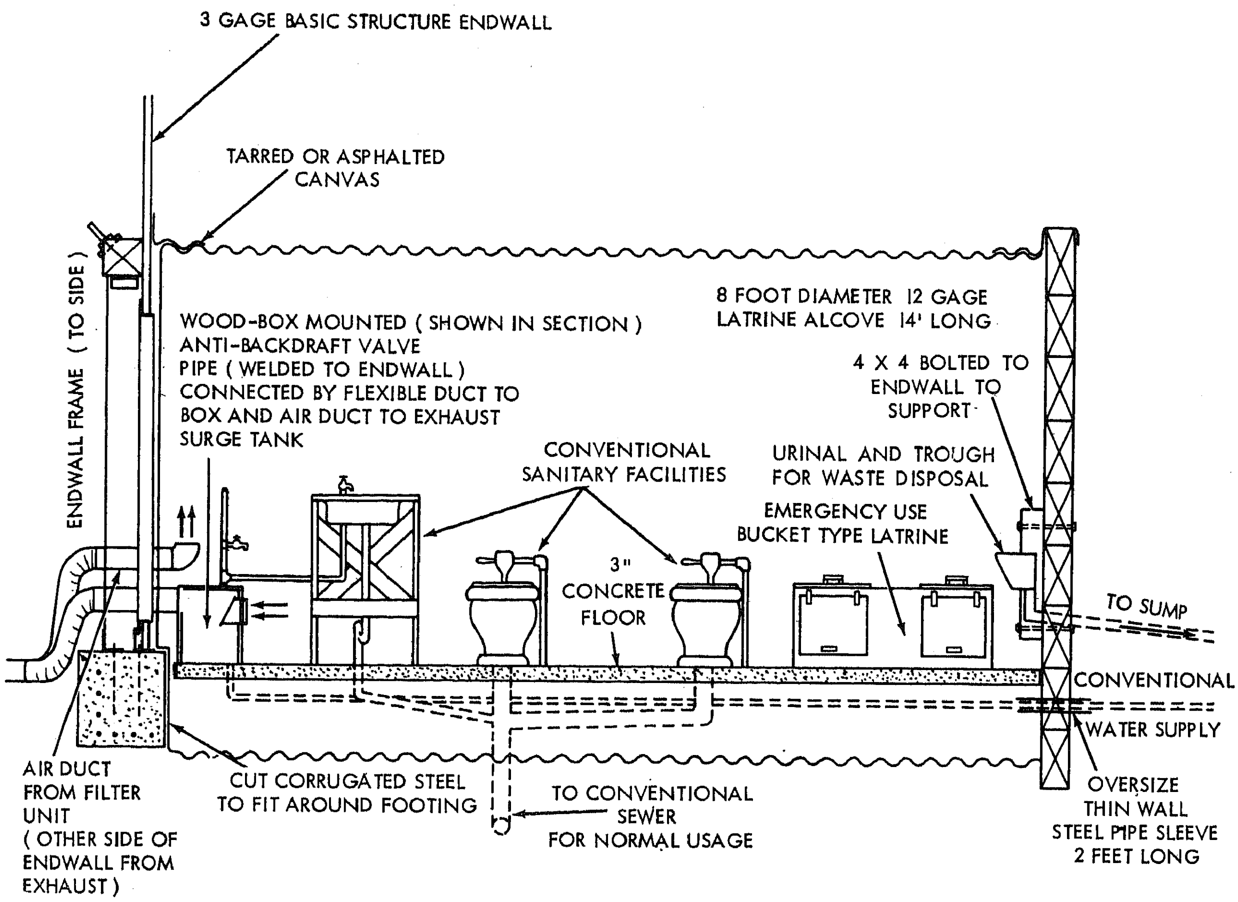


Figure 159. Latrine alcove, continuous occupancy working station.

(3) Personnel entrance—Use the details given in figures 142 and 158. The air lock is recommended. Check the gage sizes required with figure 127 for the given radii and overpressure. Substitute heavier gage if the required gage is not available.

h. Personnel Hatch Details. The designed personnel hatch shown in figure 144 or the stock steel hatch shown in figure 145 is recommended.

i. Alcove Details. The latrine details recommended are given by figure 159. For this shelter, shower facilities are optional. The storage alcove can be constructed similar to the latrine alcove. For the alcoves, figure 127 should be used to check the adequacy of available gage sizes.

147. Examples of Utilities Requirements

a. Air Treatment Equipment for Normal Operating Conditions.

(1) *Air Vitiation.* The ventilation requirement for normal operating conditions is 10 cfm (0.28 cu m/min) per person (para 92*c*(1)).

$$16 \text{ persons} \times \frac{10 \text{ cfm}}{\text{person}} = 160 \text{ cfm}$$

(4.5 cu m/min)

The M6A1 filter unit, rated at 300 cfm (8.5 cu m/min) provides the proper ventilation to dilute the carbon monoxide concentration and supply proper oxygen. In both the air intake exhaust pipes, antiblast closure valves and surge tanks are required

with a 300-cfm rating. See figures 86 and 96 for details.

(2) *Trial air condition calculations.* For normal operations assume that thermal equilibrium exists between the shelter and surrounding soil, that is, no heat is lost to the soil. From table XIX, determine that the 16 operations personnel release a total of 1,000 BTU/hr (252,000 cal/hr) each.

16 persons × 1,000 BTU/hr (252,000 cal/hr) = 16,000 BTU/hr (4,032,000 cal/hr)

Heat load carried into the shelter by the ventilation air:

Dry bulb temperature outside = 90°F. (32.2°C.).

Dry bulb temperature inside = 75°F. (24°C.).

Assuming that the relative humidity is held to 50 percent or lower, the sensible heat load due to the maximum predicted outside conditions is calculated by:

$$H_s = \frac{Q\ (\text{cmf}) \times 60\ \text{min/hr} \times \Delta t}{50}$$

(MS filter unit, Q = 300 cfm or 8.5 cu m/min)

$$H_s = \frac{(300)\ (60)\ (90°–75°)}{50} =$$

5,400 BTU/hr (1,360,800 cal/hr)

The total heat load for which air-conditioning equipment must be provided is as follows:

Sensible heat load (table XXXIV): Cal/hr (personnel and equipment)	91,329 BTU/hr or 23,014,900
	5,400 BTU/hr or 1,360,800 cal/hr (outside air)
Latent heat load (table XXXIV):	4,000 BTU/hr or 1,008,000 cal/hr (personnel)
Total:	100,729 BTU/hr or 25,383,700 cal/hr

$$\text{Sensible heat ratio} = \frac{\text{Sensible heat load}}{\text{total heat load}}$$

$$= \frac{96,729}{100,729} = 0.962$$

$$\text{or, } \frac{24,375,700}{25,383,700} = 0.962$$

Since the sensible heat ratio is less than one, a conservative selection of the air-conditioning equipment can be made from table XXII.

Note. Although a reduction in the heat load is permitted for a sensible heat ratio less than 1.0, as explained in paragraph 101*f* the 0.6 is so nearly equal to unity that this reduction is neglected.

Select one 38,000 BTU/hr (9,576,000 cal/hr) and two 32,500 BTU/hr (8,190,000 cal/hr) air conditioning units, giving a total of 103,000 BTU/hr (22,956,000 cal/hr). It is preferable to select several medium size units rather than one large unit for reasons of reliability and flexibility. If a duct-work distribution system is connected to the output of the air conditioners, a reduction in the cooling capacity must be considered due to the resistance within the duct-work (104*d* and table XXIV).

Table XXXIV. Trial Heat Load Tabulation (Personnel and Equipment) for Normal Operating Conditions

Source	Power (in KW)	Efficiency factory (assumed)	Sensible heat		Latent heat	
			BTU/hr	Cal/hr	BTU/hr	Cal/hr
Personnel*	---	---	12,000	3,024,000	4,000	1,008,000
Equipment:						
Signal	20	1.0	20 KW: 68,240	17,196,480		
Lights	2	1.0	2 KW: 6,824	1,719,648		
Filter**	1.25	1.0	1.25 KW: 4,265	1,074,780		

Table XXXIV. Trial Heat Load Tabulation (Personnel and Equipment) for Normal Operating Conditions—Continued

Source	Power (in KW)	Efficiency factory (assumed)	Sensible heat		Latent heat	
			BTU/hr	Cal/hr	BTU/hr	Cal/hr
Air conditioner (assumed value)	6	0.26	Heat generated is considered in net capacity of the air conditioner			
Totals	29.25	---	91,329	23,014,908	4,000	1,008,000

* The separation of personnel heat load into sensible and latent heat is made in proportion to the values given in table XX.

** See table XVIII.

b. Air Treatment Equipment for Emergency Operating Conditions.

(1) *Air vitalization.* Under emergency conditions, the shelter must house 62 persons. A ventilation of 3 cfm (0.08 cu m/min) per person is required to dilute the carbon dioxide and supply oxygen—62 persons × 3 cfm/person = 186 cfm (5.27 cu m/min). Therefore, using table XVIII, it is evident that the M6A1 (E24) filter unit, rated at 300 cfm (8.5 cu m/min) is adequate.

(2) *Trial air-condition calculations.* Assume that half of the personnel are active and half are at rest—

44 persons × 400 BTU/hr/person = 17,600 BTU/hr.
16 persons × 1,000 BTU/hr/person = 16,000 BTU/hr.
Total heat load for personnel = 33,600 BTU/hr.

Or,
44 persons × 100,800 cal/hr/person = 4,435,200 cal/hr.
16 persons × 252,000 cal/hr/person = 4,032,000 cal/hr.
Total heat load for personnel = 8,467,200 cal/hr.

Heat load carried into the shelter by the ventilation air — Since 90°F. (32.2°C.) DB and 75°F. (24°C.) ET are permitted under emergency conditions, the equation for sensible heat load ($H_s = \frac{Q \times 60 \times \Delta t}{50}$ becomes zero because Δt is equal to zero. The total heat load therefore is: 97,829 BTU/hr + 15,100 BTU/hr = 112,929 BTU/hr (table XXXV). The sensible heat ratio is: $\frac{97,829}{112,929} = 0.868$, which permits a reduction of 1.3 × 5% = 6.5% (para 101). Therefore the total heat load is: 0.935 x 112,929 BTU/hr = 105,500 BTU/hr, which is more than the 103,000 BTU/hr provided for normal conditions by one 38,000-BTU/hr and two 32,500-BTU/hr air conditioners. This small difference is considered acceptable.

Or, 24,652,908 cal/hr + 3,805,200 = 28,458,108 cal/hr (table XXXV). The sensible heat ratio is: $\frac{24,652,908}{28,458,108} =$ 0.868, which permits a reduction of 1.3 x 5% = 6.5% (para 101). Therefore, the total heat load is: 0.935 x 28,458,108 cal/hr = 26,608,331 cal/hr, which is more than the 25,956,000 cal/hr provided for normal conditions by the air conditioners (para 147*a*(2)).

c. Air Treatment Considerations for Disaster Conditions. Concerning the allowable stay time with no ventilation, the gross volume per person $= \frac{9814 \text{ cu ft}}{62 \text{ persons}} = 158$ cu ft/person, or $\frac{277.9 \text{ cu m}}{62 \text{ persons}} = 4.47$ cu m/pers. Figure 100, with

volume at 160 cu ft/person (46 cu m/person) and terminal carbon dioxide concentration of 5 percent, indicates the allowable stay time is 9 hours with no ventilation. The corresponding oxygen concentration is 14.7 percent, which is greater than the 10 percent minimum.

Table XXXV. Trial Heat Load Tabulation (Personnel and Equipment) for Emergency Operating Conditions

Source	Power (KW)	Efficiency factory (assumed)	Sensible heat		Latent heat	
			BTU/hr	Cal/hr	BTU/hr	Cal/hr
Personnel*	---	---	18,500	4,662,000	15,100	3,805,200
Equipment:						
Signal	20	1.0	20 KW = 68,240	17,196,480		
Lights	2	1.0	2 KW = 6,824	1,719,648		
Filter	1.25	1.0	1.25 KW = 4,265	1,074,780		
Air conditioner	23.4					
Totals	46.65	---	97,829	24,652,908	15,100	3,805,200

* The separation of personnel heat load into sensible and latent heat is made in proportion to the value given by table XX.

d. Electric Power Requirements.

(1) *Tabulation of power equipment:*

Signal equipment	20 KW
Lighting	2 KW
M6 Filter Unit	1¼ KW
3 air conditioners	23.4 KW
Total power required	46.65 KW

(2) *Generator selection.* On the site there exist two 30-KW units, and supply has two more 30-KW units (para 137*a*(2)). The most desirable plan would be to place 60 KW of generating equipment (two-30-KW) in a protective pit to be used only in emergency. The two 30-KW units located in the existing aboveground building can be used for normal operations.

(3) *Generator pit details.* A generator pit, separate from the main shelter is required due to the heat produced by the engine-generator operation. Currently, there is no pracical means for removing this added heat load if the engine-generator set were in the main shelter. Ideally, the generator should have the same degree of protection given the personnel or equipment within the shelter. Thus, the problem is to provide as much protection as possible and also provide for cooling and exhaust for the engine generator set. Two solutions seem practical, even though not completely satisfactory. The first practical solution is to place the generator in a pit with a fuel line connected to a buried fuel-storage tank. This solution has been tested to 30 to 50 psi (2 to 3.5 kg/sq cm) and the generators survived with minor, but reparable, damage. The occupants must be prepared to make these minor repairs. This is the solution recommended with this practical exercise. The second practical solution is to separate the radiator and fan from the engine-generator set. The engine-generator could then be placed within an alcove off the main shelter, and the radiator and fan or cooling tower could be placed in an external pit. The coolant for the engine would then be circulated through the pipes between the radiator and the engine of the engine-generator set. A steel grill should be placed over the radiator pit to protect it from falling debris. This solution allows some of the heat from the engine-generator to reach the alcove. Since housing two generators (one 30-KW and one 15-KW) is antici-

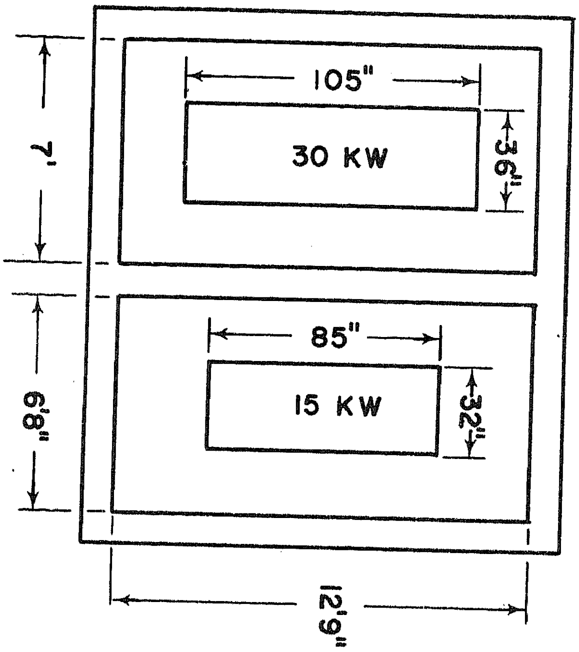


Figure 160. Generator pit.

pated, a single pit for both require the least effort. Allowing at least 2 feet of working space on all sides of each generator, the inside dimensions of the pit are as shown in figure 160. Allowing 3 inches for an overhead steel grill, the inside pit depth is 66 in. + 24 in. + 3 in. = 93″, or 7′9″ (2.3 m).

148. Attentuation Factor for Initial Nuclear Radiation

a. Initial Gamma Radiation.

(1) Attenuation through roof (para 51).
AF_r = Right angle turn factor = .07
AF_{soil} = Assume 6′* (soil) = .001
$AF_{corrugated\ metal}$ = (7 ga = .18 in) = 1.0
$AF_{total} = .07 \times .001 \times 1.0 = 7. \times 10^{-5}$

(2) AF_t through entrance way
AF_r = Right angle turn = .07
AF_a = Ratio of area = $\frac{\text{Smallest diameter area}}{\text{Largest shelter area}}$ =

$$\frac{\frac{\pi (3)^2}{4}}{\frac{\pi (25)^2}{2 \times 4}} = .029$$

$AF_{steel\ hatch}$ = AF (½″ steel = .9 × .9) = .81
$AF_{total} = AF_r \times AF_r \times AF_r \times AF_r \times AF_{sh} \times AF_{sh} \times AF_a$
$AF_{total} = .07 \times .07 \times .07 \times .07 \times .81 \times .81 \times .029 = 4.56 \times 10^{-7}$
Total AF for gamma radiation
$AF_{tot} = 7 \times 10^{-5} + .0456 \times 10^{-5} = 7.0456 \times 10^{-5}$

b. Initial Neutron Radiation Attenuation Factor.

$AF = 1 \times 10^{-4}$

(* Assume 6′ of soil since it more closely approximates the cover over shelter.)

APPENDIX I

REFERENCES

1. DA Pams

DA Pam 39–2	The Effects of High Yield Nuclear Explosions.

2. AR's

AR 320–5	Dictionary of United States Army Terms
AR 320–50	Authorized Abbreviations

3. FM's

FM 3–10	Chemical and Biological Weapons Employment
FM 3–12	Operational Aspects of Radiological Defense
FM 5–15	Field Fortifications
FM 5–20	Camouflage, Basic Principles and Field Camouflage.
FM 5–34	Engineer Field Data
FM 21–40	Small Unit Procedures for Chemical, Biological, and Radiological (CBR) Operations
FM 21–41	Soldier's Handbook for Chemical and Biological Operations and Nuclear Warfare
FM 21–48	Chemical, Biological, and Radiological (CBR) and Nuclear Defense Training Exercises

4. TM's

TM 3–210	Fallout Prediction
TM 3–220	Chemical, Biological, and Radiological (CBR) Decontamination
TM 3–4240–203	Accessory Equipment for Protective Shelters
TM 3–225	Radiological and Disaster Recovery Operations at Fixed Military Installations
TM 5–315	Firefighting (Structures and Aircraft) and Rescue Operations

5. Miscellaneous

Fallout Shelter Survey, Guide for Architects and Engineers, Office of Civil Defense

Shelter Design and Anaylsis, TR–20, Vol. 1, Office of Civil Defense

Design of Underground Installations in Rock, Tunnels and Linings, Corps of Engineers, U.S. Army, EM 1110–345–461

Studies in Atomic Defense Engineering, NAVDOCKS, P–290, Department of Navy, Bureau of Yards and Docks

EM 120–1–1, Engineer Capabilities Plan, Corps of Engineers, U.S. Army

Radiological Safety Manual, U.S. Army Biological Laboratories, Frederick, Maryland, AD No. 438147

AFSWC–TDR–62–138, Principles and Practices for Design of Hardened Structures

Engineer Study of Atomic Blast Resistant Design for Several Different Building Types, Ammann and Whitney. Report submitted to OCE under contract DA–49–129–Eng–317

Analysis and Design of Flexible Underground Structures, prepared by N.M. Newmark and Associates, Urbana, Illinois, Waterway Experiment Station, Corps of Engineers, Vicksburg, Mississippi

Marks' Mechanical Engineers' Handbook, McGraw-Hill, New York Krynine and Judd, Principles of Engineering Geology and Geotechnics, McGraw-Hill, New York

Note. For further information consult the following organizations or agencies:
Office of Chief of Engineers
Defense Atomic Support Agency
ASCE publications
Office of Civil Defense

INDEX

	Paragraphs	Page
Acoustical treatment	105	155
Air blast (*See Blast*)		
Air conditioners:		
Cooling load	101*b*, *c*	147
Data	101*f*	149
Design conditions	101*a*	147
Operating criteria	101*e*	149
Physical dimensions	102	149
Selection	101	147
Self-contained	100	146
Unit selection	101*d*	147
Air conditioning, mechanics	99	146
Air revitalization:		
Materials	98	144
Systems	98*a*	144
Air supply in disaster conditions	97, 98	144
Airlocks	88	123
Air vitiation	92*a*	135
Alpha particles	30*b*, 46*a*	37, 56
Angular distribution	34*e*	41
Apertures, contribution in shielding calculations	54	67
Arch:		
Design	124, 146*b*	173, 212
Gage selection	123*b*	172
Steel corrugated	123	172
Arching effect	81*e*	113
Azimuthal sectors	53	65
Backfill control	130*d*	190
Ball of fire (*See Fireball*)		
Barrier shielding	49*e*	58
Bedding planes	73*c*	102
Berms	130*b*	188
Beta particles	30*b*, 46*a*	37, 56
Biological agents, protection against	5*b*	4
Blast	22–29	22–37
Blast closures	128	180
Blast loading:		
Aboveground structures	27	31
Buried structures	28	33
Definition	25	26
Response of structures	25*a*, 26	26, 29
Semiburied structures	29	37
Underground structures	28*b*(3), *c*, *d*, *e*, *f*	36
Blast wave:		
Contact surface burst	24*d*	26
Damage	24*c*	26
Formation and breakaway	22*a*	22
General description	22	22

	Paragraphs	Page
Blast wave—Continued		
Reflection	24	26
Subsurface burst	24*e*	26
Bolting	74*b*(2)	105
Breakaway	22*a*	22
Buried structures	28*b*, 131–133	35, 191–197
Central roof area contribution	51*b*	64
Cesium-137	47*a*	57
Chemical control, advantages	92*c*(2)	136
Chemical environment	92	135
Chemical tolerance limits	92*b*	136
Combined shielding	49*g*	59
Communications	118	167
Concealment	17*c*, 18*d*, 19*e*	16, 18, 21
Conductors	112	160
Construction material	82*b*	116
Contamination:		
Area	45*c*(4)	56
Distribution	45*c*(3)	56
Modes	45*c*	55
Conventional weapons, protection from	4*a*, *b*	3
Cover criteria	121	170
Deadman endwall support	127	177
Decontamination	90	127
Delayed fallout:		
Characteristics	47	57
Influence of atmosphere	47*b*	57
Delayed neutrons	36	43
Density of ignition points	42*a*(2)	52
Diffraction loading	25*b*, 27*a*	27, 31
Doors	128, 129	180, 184
Dose-distance relationship, gamma rays	32	38
Dose, infinity	45*b*	55
Dose transmission factor	34	40
Drag loading	7*a*, 25*c*, 27*a*	4, 29, 31
Duckboards	126*b*	175
Duct diameter	104*d*	154
Duct systems:		
Air supply	104*a*	154
Characteristics	103	154
Design	104	154
Materials	104*b*	154
Protection against fallout	104*f*	155
Resistance	104*d*	154
Velocities	104*c*	154

	Paragraphs	Page
Dynamic loading:		
Aboveground structures	81*d*	113
Buried structures	81*e*	113
Nuclear and conventional	81*a*	112
Semiburied structures	81*e*	113
Types	81	112
Dynamic pressure	23	22
Early fallout fraction	45*c*(2)	56
Earth contamination	45*c*(1)	55
Earth cover:		
Backfill control	130*d*	190
Berms	130*b*	188
Description	130, 146*f*	188, 212
Foundations	130*e*	190
Material	130*c*	188
Elasto-plastic action	82*c*	118
Electric power:		
Aboveground installations	111	159
Belowground installations	110	158
Conductors	112	160
Electric power and lighting	109	156
Electricity	109	156
Emplacements, covered, loss of protection	7*b*(4)	7
Emplacements, open, loss of protection	7*b*(3)	6
Endwall	127	177
Energy, forms	21	22
Entrances, mines, tunnels, caves:		
Drawbridge door	79*c*	111
Vertical shaft	79*a*	109
Walk-through door	79*b*	110
Entranceways	128	180
Environmental engineering	91–119	135–168
Estimating heat transfer	41, 42, 93, 147	48, 52, 136, 214
Example design	134–148	203–218
Exit, emergency, filled tube	128*d*, 146*g*(2)	182, 212
Expedient shelters:		
Conventional buildings	60, 61	78, 79
Entranceway improvements	65	87
Existing facilities	58, 59	78
Improvement example	68	96
Improvement	63, 64	80, 83
Recommendations	62	80
Expedient shelters, basements:		
Allowable overpressure	67	90
Cap and base plate design	66	89
Characteristics	63	80
Explosion, atomic (or nuclear)	20, 21	22
Facilities:		
Categories	58*c*	78
Existing	58*b*	78
Utilization concept	58	78
Fallout:		
Activity and decay	45*a*	55
Delayed	47	57
Distribution	45*c*	55
Early	44	55
Fallout—Continued		
Patterns	45*d*, *e*	56
Protection	8*b*, 10*b*, 16*a*, 17*b*, 18*c*, 19*d*	9, 15, 16, 18, 21
Faults	73*c*(1)	102
Filters, air	140*c*	207
Filter units:		
Installation	87, 107	122, 156
Performance	106	156
Pressurization	108	156
Types	86, 106	120, 156
Fireball	22	22
Fission process	8	8
Flame, shelter against	5*a*	4
Flooring:		
Selection	146*c*	212
Types	126	175
Folds	73*c*(2)	102
Food supply	117	167
Footings	125, 146*c*	174, 212
Fortifications:		
Adaptation as shelters	70, 71	99
Biological protection	12*d*	11
Character	70	99
Chemical protection	12*d*	11
Foundations, earth	130*e*	190
Frames, blast resistant	129	184
Fusion process	8	8
Gamma radiation:		
Attenuation of entranceway	35*a*	41
Attenuation through earth cover	35*d*	43
Definition	46*b*	56
Gamma rays:		
Definition	30*b*	37
Shielding	33	39
Generators	109*b*	158
Geometry shielding	49*f*	59
Gooseneck intake	104*f*	155
Ground contribution	52, 56	64, 73
Horizontal passageways, contribution shielding calculations	57	75
Incident and reflected waves	24*a*	26
Initial gamma radiation	8*a*	8
Initial gamma-ray shielding	35	41
Initial gamma rays, rate of delivery	30*b*	37
Initial radiation:		
Description	30–39	37–45
Protection	8	8
Installations:		
Area dispersed	19	18
Linearly dispersed	17	16
Point dispersed	18	16
Undispersed	16	15
Irregular reflection	24*b*	26
Latrines, chemical	114	164
Linings	74*a*	103

	Paragraphs	Page
Loading:		
Blast	25	26
Diffraction	25b	27
Drag	25*c*	29
Response	25*a*	26
Structures	26	29
Loadings	80*b*	112
Mach effect	24*b*	26
Mach stem	24*b*(2)	26
Mass thickness	49*e*(3), 107	58, 156
Negative phase	22*a*	22
Neutron radiation, protection	8*b*	9
Neutron shielding, test structures	39	45
Neutrons:		
Attenuation	37	43
Definition	30*b*	37
Delayed	36	43
Prompt	36	43
Shielding against	37	43
Shielding materials	38	43
Sources	36	43
Nuclear radiation	30	37
Nuclear weapons effects, comparison protection	11	10
Overhead cover:		
From artillery and infantry weapons	4*a*, *b*	3
Permanent	10*b*(3)	10
Temporary	10*b*(4)	10
Overpressure:		
Description	7*a*(1), 22*b*	4, 22
Negative	81*c*	113
Peak	22*b*	22
Side-on	25*b*	27
Peak overpressure	22*b*	22
Peripheral roof area contribution	51*b*	64
Pressure control devices	89	124
Protection:		
Administrative support installations	15	14
Comparison	11, 12	10
Protection factor	50	61
Protection:		
Blast effects	7	4
Bombs and aerial missiles	4*b*	3
Chemical and biological weapons	5, 83–90	4, 120–127
Debris	7*b*(2)	6
Drag loading	7*a*(2)	6
Flame	5*a*	4
Gas, liquid contaminants, biological agents	5*b*	4
Napalm and flamethrower	5*a*	4
Nuclear weapons	6–10	4–9
Overpressure	7*a*(1)	4
Physical injury	7*b*(1)	6
Tracked vehicles	4*c*	4
Protective layout of installations:		
Area dispersed	15*d*(4), 19	15, 18
Characteristics	15*d*	15
Linearly dispersed	15*d*(2), 17	15, 16
Point dispersed	15*d*(3), 18	15, 16
Undispersed	15*d*(1), 16	15
Protective measures:		
Airlocks	88	123
Concealment	13*c*	13
Dispersion	13*a*	12
Duplication	13*b*	13
Engineer responsibility	14*b*(1)	13
Field fortifications	14*a*	13
Filtering	85–87	120–122
Priority determination	14*b*(2)	13
Sealing	84	120
Superimposition	13*d*	13
Protective structures, ventilation and space requirements	145*a*	210
Psychrometric, use	93*c*	140
Radiant exposure	41*b*(1)	5
Radiation:		
Dose rate	45*a*(4), *b*	5
Gamma	46*b*	56
Radiological defense equipment	119	168
Rad	31	37
Reduction factor	50*b*	61
Reflected pressures	25*d*	29
Residual nuclear radiation:		
Attenuation	46	56
Protection	48	57
Sources	43	54
Residual number (*See Reduction factor*)		
Rock	73	101
Roentgen (*See Rad*)		
Roof contribution	51	61
Sanitation	115	165
Sanitation systems	113	164
Sealed-in periods	97	144
Shelter	3	2
Shelter components, selection	135	203
Shelter design	80–82	112–115
Shelters:		
Conventional pillboxes	71*c*	101
Existing facility concept	58, 59	78
Fortifications	70, 71	99
Habitable	91	135
Purpose in field	3	2
Semipermanent	14*a*(3)	13
Subsurface	7*b*(6)	7
Surface	7*b*(5)	7
System	7*b*(7)	7
Use of caves	78	109
Use of mines	76	105
Use of tunels	77	108
Shielding, residual nuclear radiation:		
Barrier shielding	49*e*	58
Combined shielding	49*g*	59

	Paragraphs	Page
Shielding, residual nuclear radiation—Continued		
Description	48	57
Detector's position	49*b*	58
Geometry shielding	49*f*	59
Mutual shielding and height effects	55	70
Source of radiation	49*c*	58
Shock	22*a*	22
Shoring	74*a*	103
Side-on overpressure	25*b*(1)	27
Skyshine	34*e*, 63*b*	41, 80
Slant range	32, 41*c*	38, 52
Stagnation pressure	25*d*	29
Standard drawings	123–129	172–184
Static loads	80*a*	112
Storage	116–119	166–168
Strength, elastic	82*c*	118
Strontium-90	47*a*	57
Structural design	82	115
Structures:		
Construction considerations	120	169
Design procedure	120*c*	169
Determining type	120*a*	169
Earth cover	130	187
Response to static and dynamic loads	82	115
Selection of components	120*b*	169
Semiburied	121*a*, *b*	170
Structures, buried:		
Circular reinforced concrete	131	191
Circular reinforced concrete arch	132	196
Rectangular reinforced concrete	133	197
Standard drawings:		
Corrugated steel	123	172
Door hatches	129	184
Structures, buried—Continued		
Standard drawings—Continued		
Endwalls	127	177
Entranceways	128	180
Floors	126	175
Footings	125	174
Steel arch	124	173
Structures and components	122	171
Superimposition	13*d*, 18*e*, 19*f*	13, 18, 21
Symbols	49*a*	58
Thermal energy-distance relationship	41*c*	52
Thermal environment	93	136
Thermal radiation:		
Absorption	41*a*	48
Attenuation	40*b*	47
Characteristics	40*a*	47
Effect of atmosphere	40*c*	47
Effect of shielding	40*e*	52
Effect of smoke and fog	40*d*	52
Incendiary effects	42	52
Protection	9	9
Type of burst	40*f*	48
Transmission factor	34, 39	40, 45
Underground openings	75	105
Underpressure	22*c*	22
Velocity head	104*d*(4)	154
Velocity pressure	104*d*	154
Ventilation, air	92*c*(1), 93*g*	136, 142
Water supply	116	166
Weapons, comparison of protection requirements	11, 12	10

By Order of the Secretary of the Army:

HAROLD K. JOHNSON,
General, United States Army,
Chief of Staff.

Official:

J. C. LAMBERT,
Major General, United States Army,
The Adjutant General.

Distribution:

Active Army:

DCSPER (2)
ACSI (2)
DCSLOG (2)
DCSOPS (2)
C/Ofc Res Comp (2)
CRD (1)
COA (1)
CINFO (1)
TIG (1)
TJAG (1)
ACSFOR (2)
CNGB (2)
CofEngrs (2)
ARADCOM (2)
ARADCOM Rgn (2)
USACDC (2)
USACDCEA (2)
USACDCEC (2)
USACDCNG (2)
USAAVNBD (2)
USAARTYBD (2)
MDW (1)
Armies (5) except
  EUSA (11)

OS Maj Comd (10) except
  USASETAF (5)
Corps (3)
LOGCOMD (1)
Div (2)
Div Arty (1)
Bde (2)
Regt/Gp/Bat Gp (2)
Bn (2)
Co/Btry (2)
Instl (1)
Engr Cen (5)
PMS Sr Div Units (1)
Svc Colleges (2)
Br Svc Sch (2) except
  USAIS (55) USACMLCS (50)
USA Sch, Europe (3)
USMA (2)
AMS (1)
USA Mbl Equip Cen (5)
USA Tng Cen (2) except Engr (50)
JUSMMAT (1)
MAAG (1)

NG: State AG (3) units—same as active Army, except allowance is one copy to each unit.
USAR: Same as active Army except allowance is one copy to each unit.
For explanation of abbreviations used, see AR 320–50.

☆ U.S. Government Printing Office: 1965— 750-511/8731A